

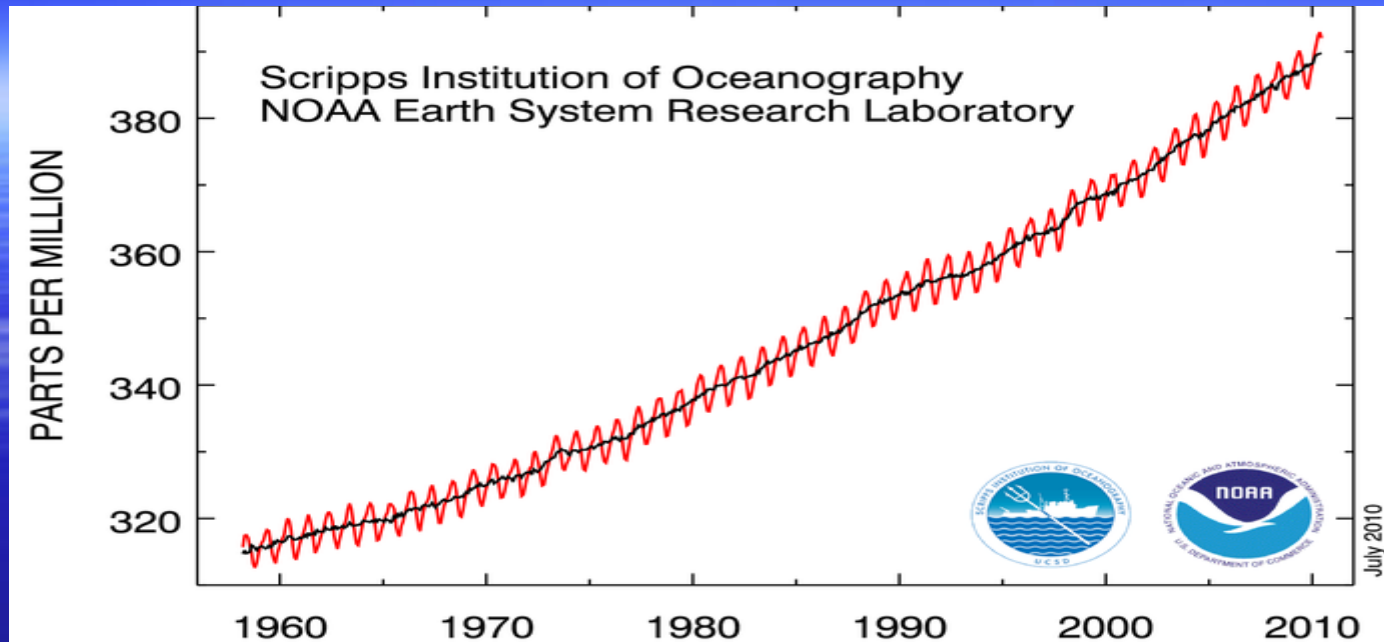
NOAA/ESRL/GMD Observations of Atmospheric Trace Constituents for Scientific Research and Global Monitoring

Sam Oltmans

**NOAA Earth System Research Laboratory
Global Monitoring Division
Boulder, Colorado**

**Federation of Earth Science Information Partners
Summer Meeting - Knoxville, TN
July 22, 2010**

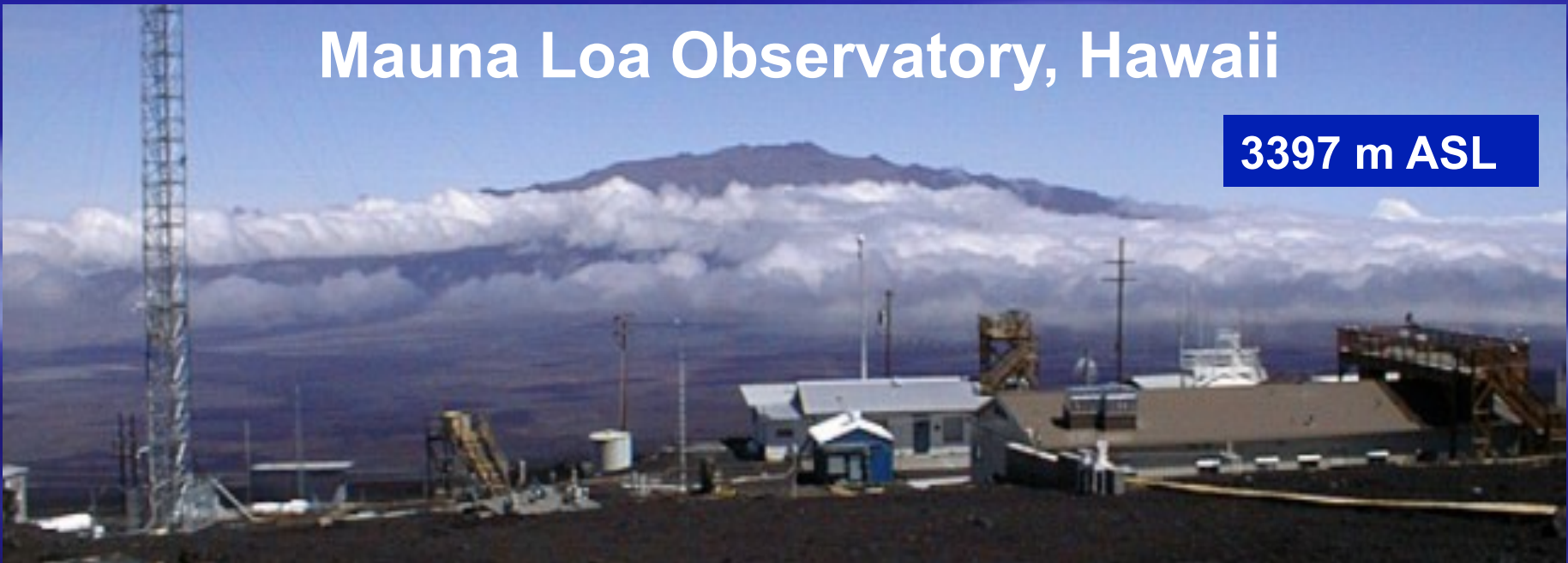
Who are we? What do we do? How do we do it?



**Atmospheric
Carbon
Dioxide,
Mauna Loa,
Hawaii**

Mauna Loa Observatory, Hawaii

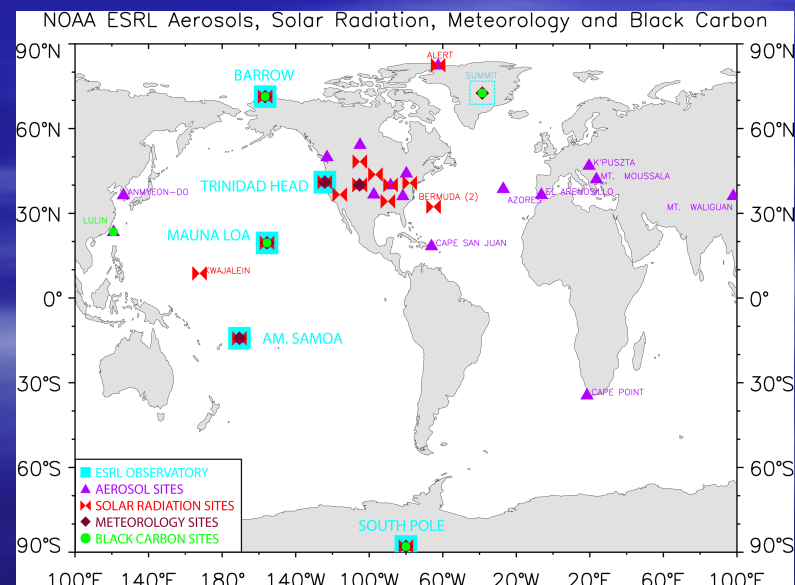
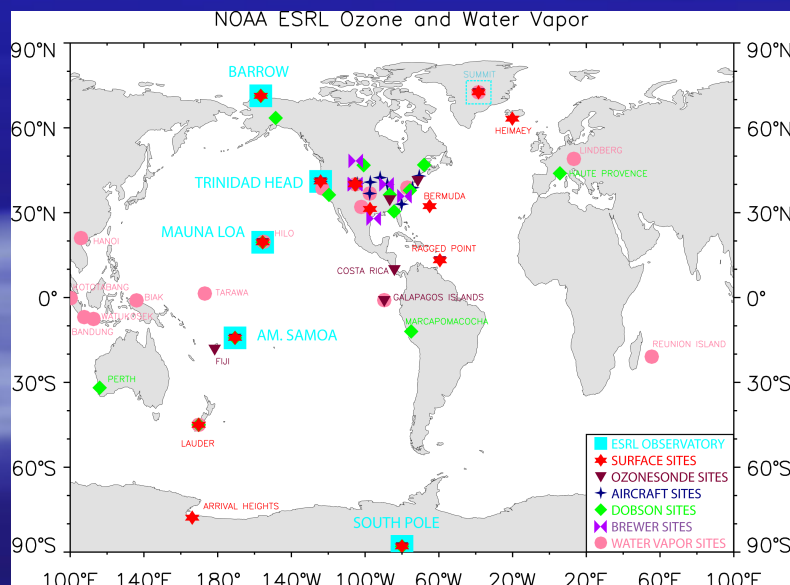
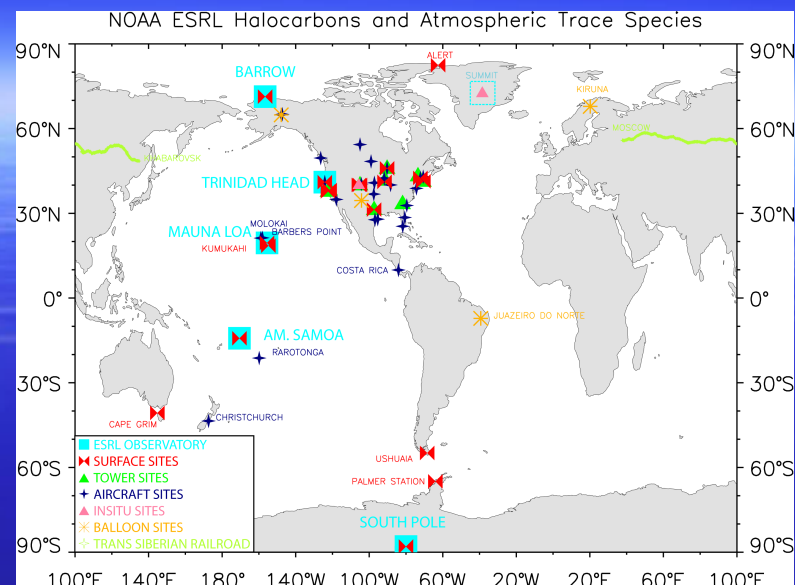
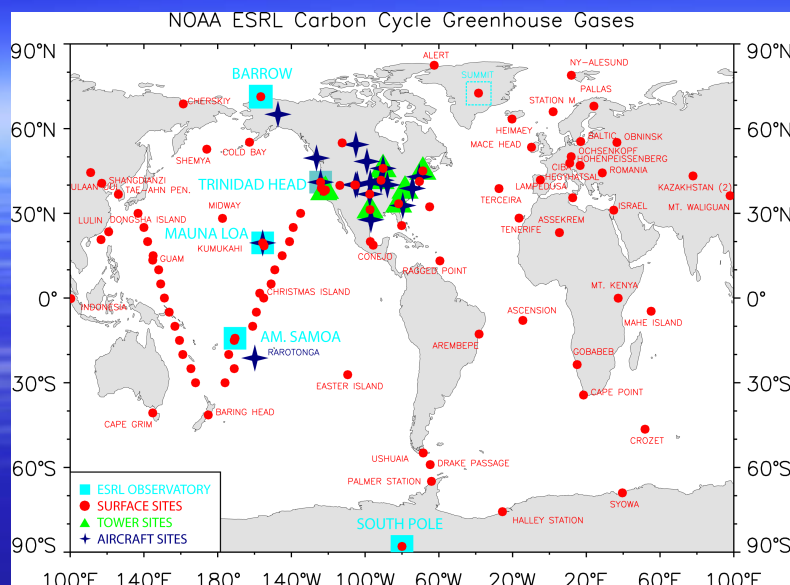
3397 m ASL



Who are we?

- Had our formal beginning as the Geophysical Monitoring for Climatic Change (GMCC) program in 1972 as part of NOAA's Environmental Research Laboratories (a number of records go back to the 1960s).
- Became a separate laboratory, the Climate Monitoring and Diagnostics Laboratory (CMDL), in 1989.
- Consolidated with several other laboratories in Boulder as the Earth System Research Laboratory (ESRL) Global Monitoring Division (GMD) in 2006.

What do we do?



GMD Observing Locations

We operate
global
networks for
observing
solar and
terrestrial
radiation and
atmospheric
constituents
that drive
climate
change,
stratospheric
ozone
depletion,
and baseline
air quality

Barrow, Alaska Baseline Observatory

Dobson Dome

Main Building

South Pole, Antarctica

2835 m ASL



Launching Water Vapor/Ozone Package at Summit



Dobson Ozone Spectrophotometer



Aerosol Lidar at Mauna Loa

Use a variety of observing platforms.

In situ:
Surface continuous and flask sampling, balloons, aircraft, tall towers and trains.

Remote sensing:
Solar and terrestrial radiation, Dobson, Brewer, lidar.

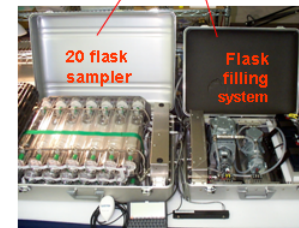


Inside the Barrow Observatory

North American Aircraft and Tall Tower Carbon Observing System



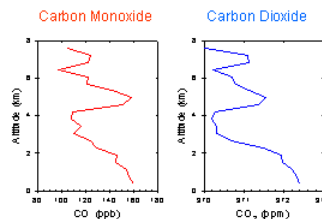
Aircraft Sampler



20 flask sampler

Flask filling system

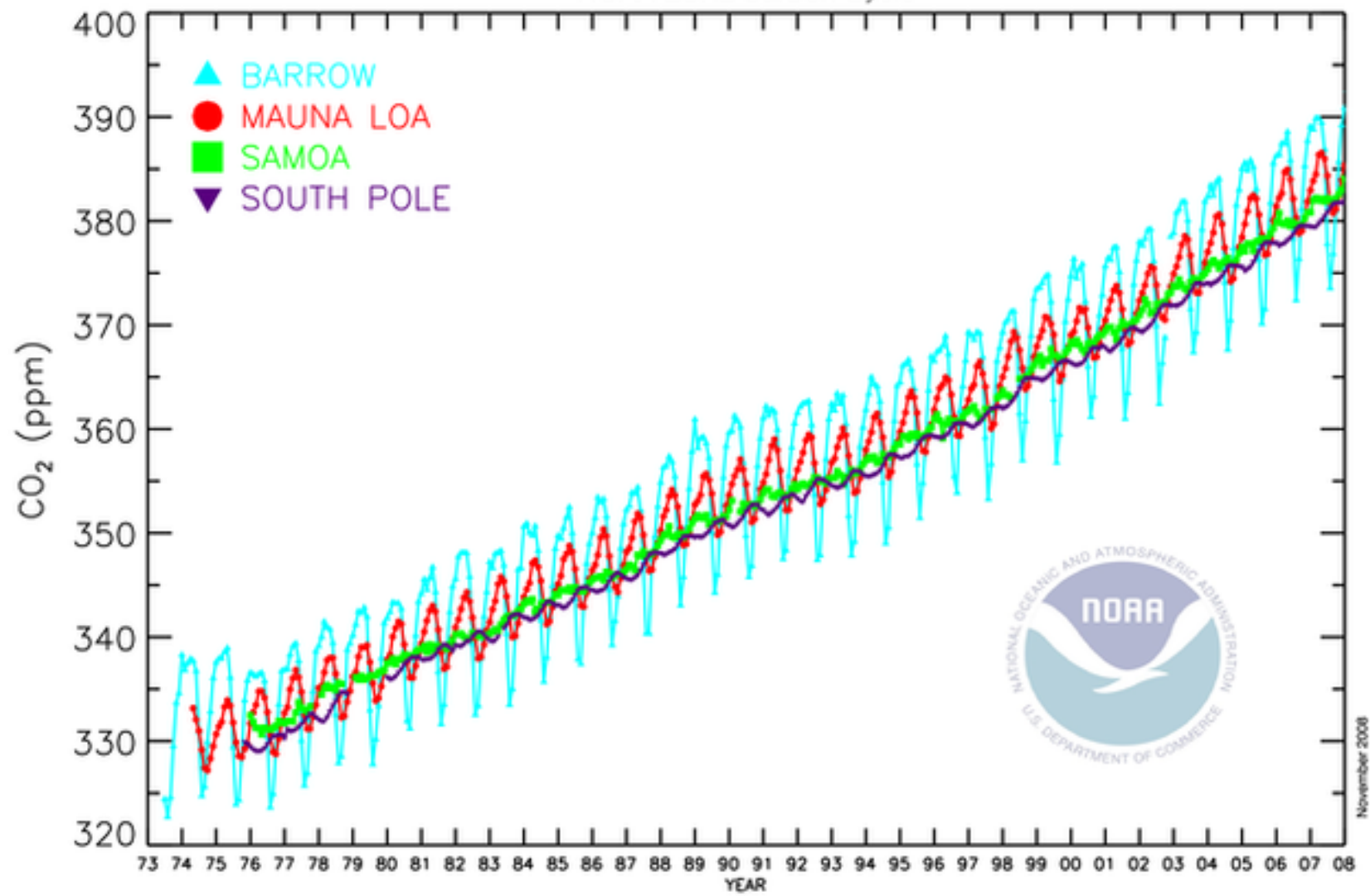
The vertical profiles of carbon dioxide, methane and carbon monoxide, are being measured at ten aircraft and three tall tower sites as part of the North American Carbon Program. The expansion of this network is underway, and when complete, will provide regional information on carbon dioxide sources and uptake in North America.



500 meter Sampling Tower

Monthly Mean Carbon Dioxide

NOAA ESRL Carbon Cycle

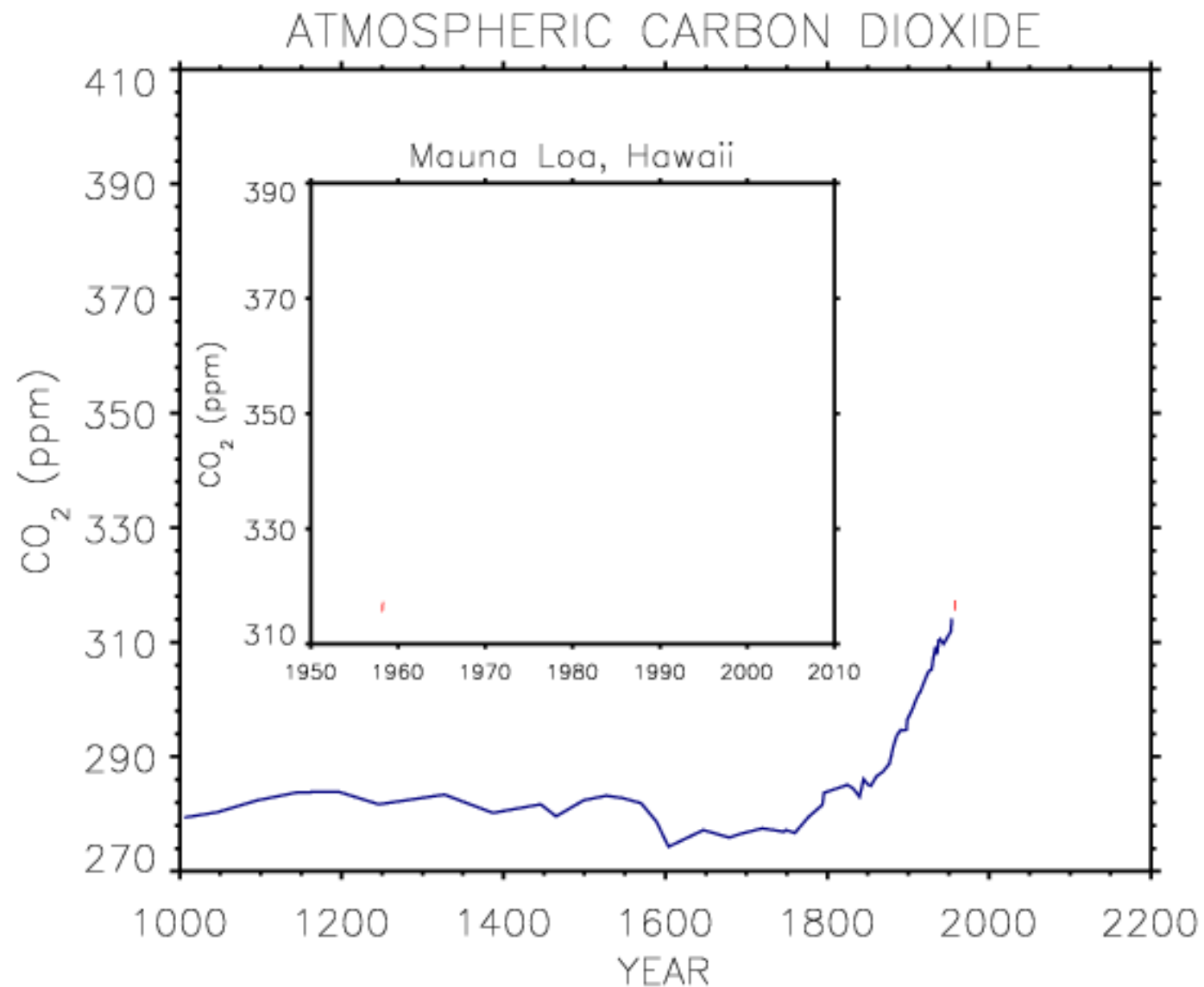


Parameters Observed at Mauna Loa

Program/Measurement	Instrument	Sampling Frequency
<i>Gases</i>		
CO ₂	Siemens Ultramat-3 NDIR analyzer*	Continuous
CO	Trace Analytical RGA3 no. R5*	Continuous
CO ₂ , CH ₄ , CO, ¹³ C/ ¹² C, ¹⁸ O/ ¹⁶ O of CO ₂ , H ₂ , N ₂ O, SF ₆ , and ¹³ C of CH ₄	2.5-L glass flasks, MAKS pump unit 2.5-L glass flasks, through analyzer AIRKIT pump unit, 2.5-L glass flasks†	1 pair wk ⁻¹
CH ₄	HP6890GC*	Continuous
SO ₂	TECO model 43-S pulsed-fluorescence analyzer; 4, 10, 23, 40 m*	Continuous
Surface O ₃	Dasibi 1003-AH UV absorption ozone monitor (End ed 08/03)* TEI Model 49 UV absorption ozone monitor* and TEI Model 49C UV absorption ozone monitor (Began 8/03)*	Continuous
Total O ₃	Dobson spectrophotometer no. 76*	3 day ⁻¹ , weekdays
O ₃ profiles	Dobson spectrophotometer no. 76* (automated Unkehr method)	2 day ⁻¹
N ₂ O, CFC-11, CFC-12, CFC-113, CH ₃ CCl ₃ , CCl ₄ , SF ₆ , HCFC-22, HCFC-21, HCFC-124, HCFC-141b, HCFC-142b, CH ₃ Br, CH ₃ Cl, CH ₃ I, CH ₃ Cl ₂ , CHCl ₃ , C ₂ Cl ₄ , H-1301, CH ₃ Br ₂ , CHBr ₃ , H-1211, HFC-134a, HFC-152a, C ₆ H ₆ , COS	Balloonborne ECC sonde 850-mL, 2.5-L, or 5-L stainless-steel flasks	1 wk ⁻¹ 1 pair wk ⁻¹
CFC-11, CFC-12, CFC-113, N ₂ O, CH ₃ CCl ₃ , CCl ₄ , CH ₃ Br, CH ₃ Cl, H-1211, SF ₆ , HCFC-22, COS, CHCl ₃ , HCFC-142b	Automated CATS GC	1 sample h ⁻¹
<i>Aerosols</i>		
Condensation nuclei	TSI 3010 CN	Continuous
Vog Monitoring Network (VOGNET)	Condensation nuclei counter (spread throughout the island)	Continuous
Optical properties	Three-wavelength nephelometer; 450, 550, and 700 nm wavelengths (TSI)	Continuous
Aerosol light absorption (black carbon)	Light absorption photometer (Radiance Research PSAP)	Continuous
Stratospheric and upper tropospheric aerosols	Aethalometer** Nd:YAG lidar: 532-, 1064-nm wavelengths	Continuous 1 profile wk ⁻¹
<i>Solar Radiation</i>		
Global irradiance	Eppley pyranometers with Q, OG1, and RG8 filters*	Continuous
Direct irradiance	Two Eppley pyrhemometers with Q filter* Eppley pyrhemometer with Q, OG1, RG2, and RG8 filters*	Continuous 3 day ⁻¹
Diffuse irradiance	Eppley/Kendall active-cavity radiometer* Eppley pyrgeometer with shading disk and Q filter*	1 mo ⁻¹ Continuous
UV solar radiation	Yankee Environmental UVB pyranometers (280-320 nm)*	Continuous
Turbidity	J-202 and J-314 sunphotometers with 380-, 500-, 778-, 862-nm narrowband filters	3 day ⁻¹ , weekdays
Column water vapor	Precision filter radiometer (368, 412, 500, 862 nm)* Two-wavelength tracking sunphotometer: 860, 940 nm (two instruments)*	Continuous Continuous
Terrestrial IR Radiation	Precision infrared radiometer, pyrgeometer*	Continuous
Solar UV Index	Davis 6160 (began 10/03)	Continuous
<i>Meteorology</i>		
Air temperature	Aspirated thermistor, 2-, 9-, 37-m heights* Max-Min thermometers, 2.5-m height	Continuous 1 day ⁻¹ , weekdays
Air temperature (30-70 km)	Lidar	1 profile wk ⁻¹
Temperature gradient	Aspirated thermistors, 2-, 9-, 37-m heights*	Continuous
Dewpoint temperature	Dewpoint hygrometer, 2-m height*	Continuous
Relative humidity	TSL, 2-m height*	Continuous
Pressure	Capacitance transducer*	Continuous
Wind (speed and direction)	10- and 38-m heights*	Continuous
Precipitation	Rain gauge, 20-cm diameter Rain gauge, 20-cm diameter‡ Rain gauge, tipping bucket*	5 wk ⁻¹ 1 wk ⁻¹ Continuous

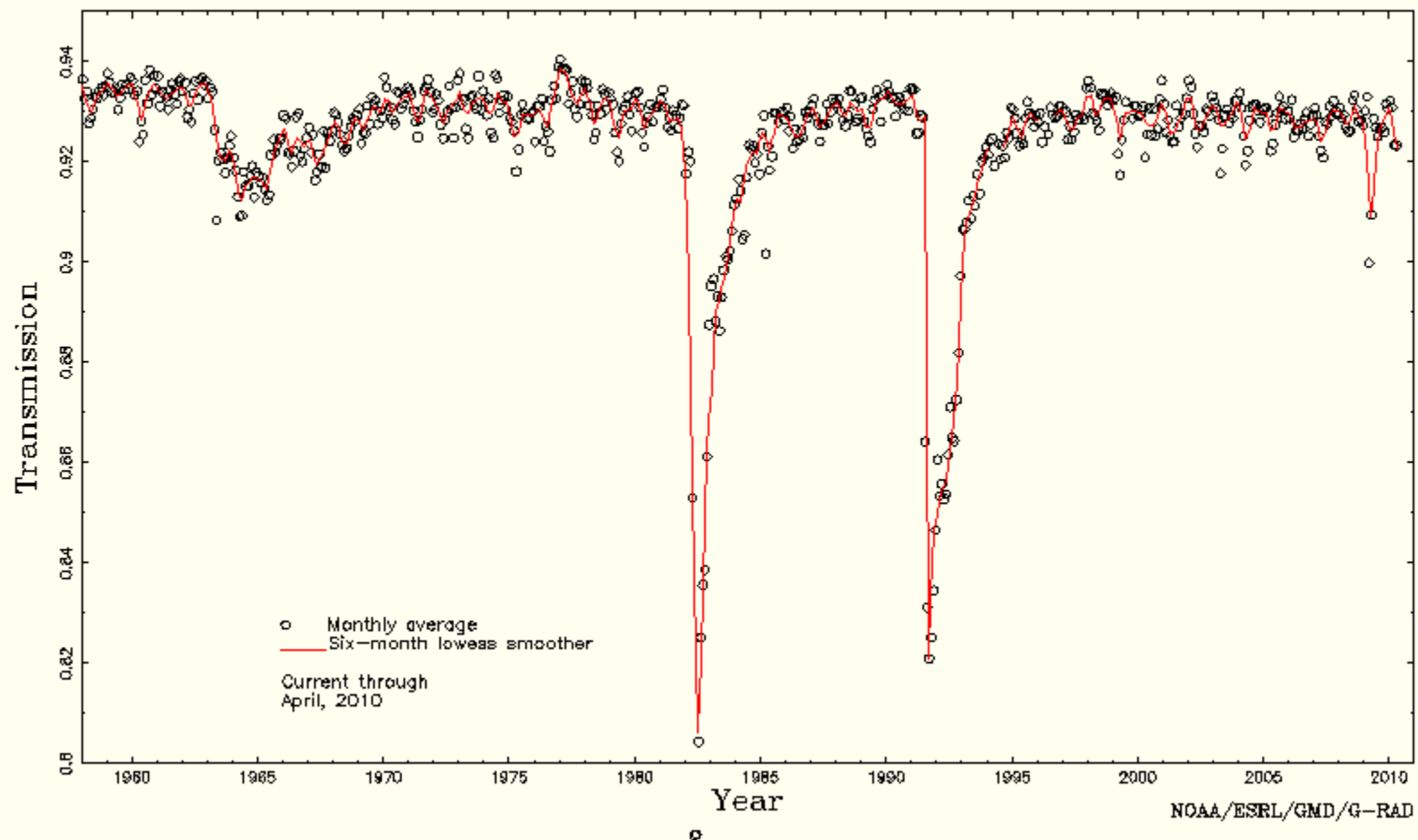
Program/Measurement	Instrument	Sampling Frequency
<i>Meteorology—continued</i>		
Total precipitable water	Foskett IR hygrometer*	Continuous
Temperature, Wind, Pressure, Precipitation, and Humidity	Davis 6160 (began 10/03)	Continuous
<i>Precipitation Chemistry</i>		
pH	pH meter	1 wk ⁻¹
Conductivity	Conductivity bridge	1 wk ⁻¹
<i>Cooperative Programs</i>		
CO ₂ (SIO)	Applied Physics IR analyzer*	Continuous
CO ₂ , ¹³ C, N ₂ O (SIO)	5-L evacuated glass flasks§	1 pair wk ⁻¹
CO ₂ , CO, CH ₄ , ¹³ C/ ¹² C (CSIRO)	Pressurized glass flask sample	3 pair mo ⁻¹
O ₂ analyses (SIO)	5-L glass flasks through tower line and pump unit§	3 (2 mo) ⁻¹
Total suspended particulates (DOE)	High-volume sampler (ended 2/03)	Continuous (1 filter wk ⁻¹)
Ultraviolet radiation (CSU and USDA)	Multi-wavelength radiometer (direct, diffuse, shadow band)	Continuous
Radionuclide deposition (DOE)	Ion-exchange column	Quarterly sample
Aerosol chemistry (Univ. of Calif., Davis)	Programmed filter sampler	Integrated 3-day sample, 1 continuous and 1 downslope sample (4 days) ⁻¹
Halides (EPA National Exposure Research Laboratory (NERL))	Sequential Fine Particle Sampler URG 2000-01J (began 05/03)	1 upslope/week and 1 downslope/week
Hg ⁰ , Hg ²⁺ , Hg ⁶ (EPA National Exposure Research Laboratory (NERL))	Tekran 2537A, 1130 and 1135p	Continuous
Particulate 2.5-10 µm (EPA NERL)	Dichotomous Partisol-Plus model 2025	1 downslope sample wk ⁻¹
Sulfate, nitrate, aerosols (Univ. of Hawaii)	Filter system	Daily, 2000-0600 LST
Radon (ANSTO)	Aerosol scavenging of Rn daughters; two-filter system*	Continuous; integrated 30-min samples
AERONET sunphotometers (NASA Goddard)	Automated solar-powered sunphotometers	Continuous
Global Positioning System (GPS) Test Bed (FAA and Stanford University)	GPS-derived column water vapor profiles	Continuous
Earthquakes (HVO-USGS Menlo Park)	Seismometer	Continuous
CO isotopes (SUNY)	1000 psi cylinder	1 (2 wk) ⁻¹
Cosmic dust (CALTECH)	Magnetic collector (ended 10/03)	1 (2 wk) ⁻¹
Volcanic activity (HVO)	Seismic and expansion instrument in 113-m-deep well	Continuous
<i>Network for the Detection of Stratospheric Change (NDSC)</i>		
Ultraviolet radiation (NOAA and NIWA)	UV spectroradiometer (285-450 nm), 0.8-nm resolution*	Continuous
Stratospheric O ₃ profiles, 20-66 km (Univ. of Mass., Amherst)	Millitech Corp., 110.8-GHz microwave ozone spectroscopy	3 profiles h ⁻¹
Stratospheric water vapor profiles, 40-80 km, 10-15 km resolution (NRL)	Millimeterwave spectrometer	Continuous
Stratospheric O ₃ profiles (15-55 km), temperature (20-75 km), aerosol profiles (15-40 km) (JPL)	UV lidar*	3-4 profiles wk ⁻¹
NO ₂ (NIWA and NOAA)	Slant column NO ₂ spectrometer	Continuous, daytime
BrO (NIWA and NOAA)	Column BrO spectrometer	Continuous, daytime
Column O ₃ , UVB (MSC, Canada)	Two Brewer spectrophotometers	Daily
Solar spectra (Univ. of Denver)	FTIR spectrometer, automated*	5 days wk ⁻¹
All instruments are at MLO unless indicated.		
*Data from this instrument recorded and processed by microcomputers.		
†Kumukahi only.		
‡Kulani Mauka.		
§MLO and Kumukahi.		
**7-wavelength aethalometer relocated to Boulder CMDL for absorption intercomparison study 4/2002.		

Ice Core and Modern CO₂ Record



Ice core record: Etheridge et al., 1996,

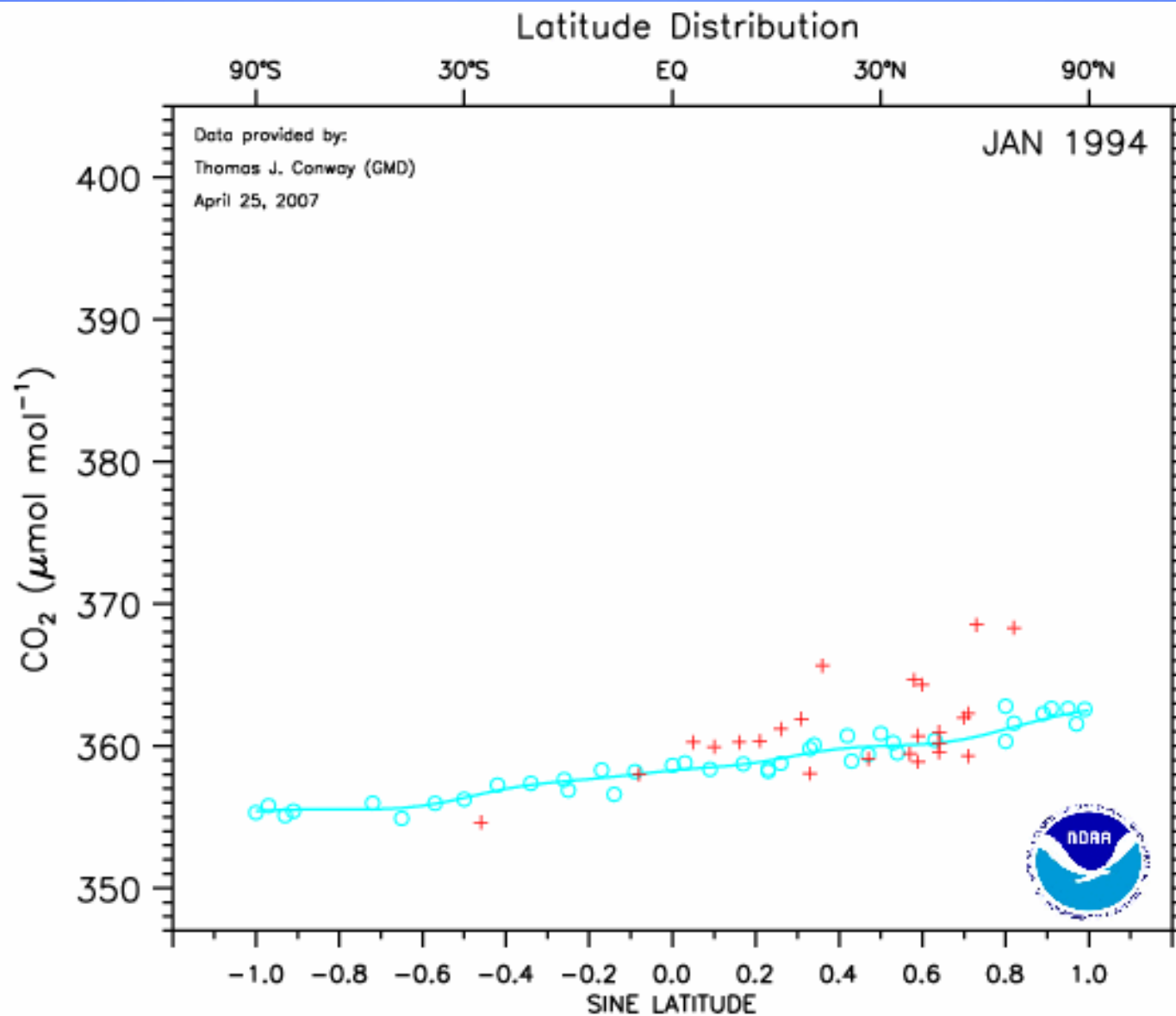
Transmission of Solar Radiation at the Mauna Loa Observatory



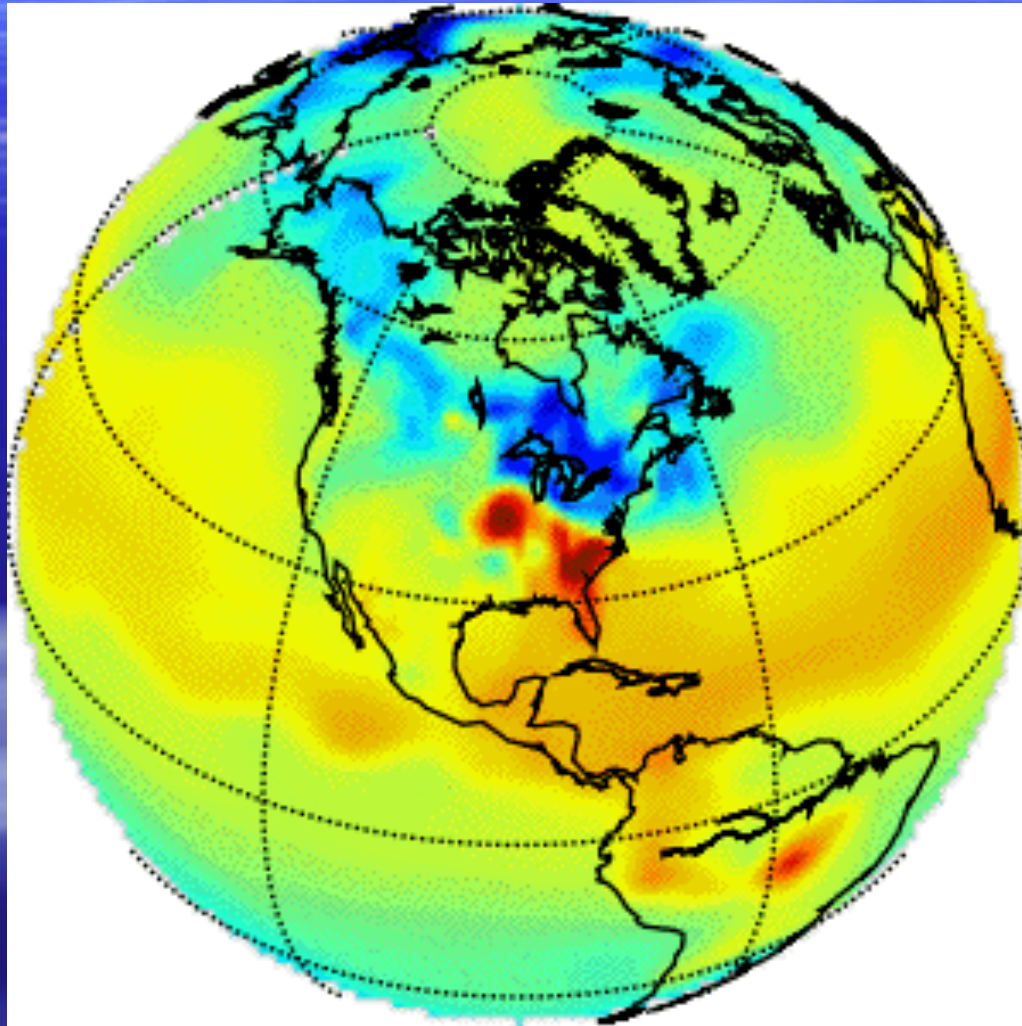
How are these data used

- Monitoring and understanding long term changes in atmospheric composition and radiative properties.
- Comparison with satellite data sets.
- Testing of atmospheric models.
- Products for public information (Greenhouse Gas Index, Ozone Depleting Gas Index) <http://www.esrl.noaa.gov/gmd/>

CO₂ Latitude Gradient



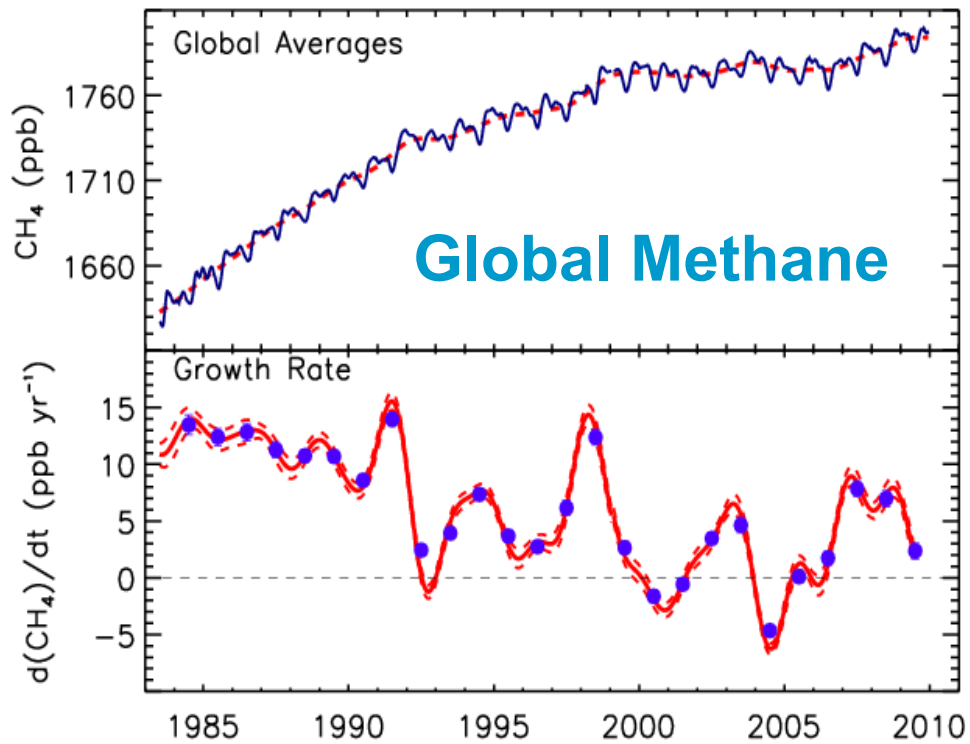
Carbon Tracker: A System to Track Carbon Dioxide Uptake and Release at the Earth's Surface Over Time.



2005 Vegetation
Spring and
Summer CO₂
Cycle. Fossil
fuels removed.

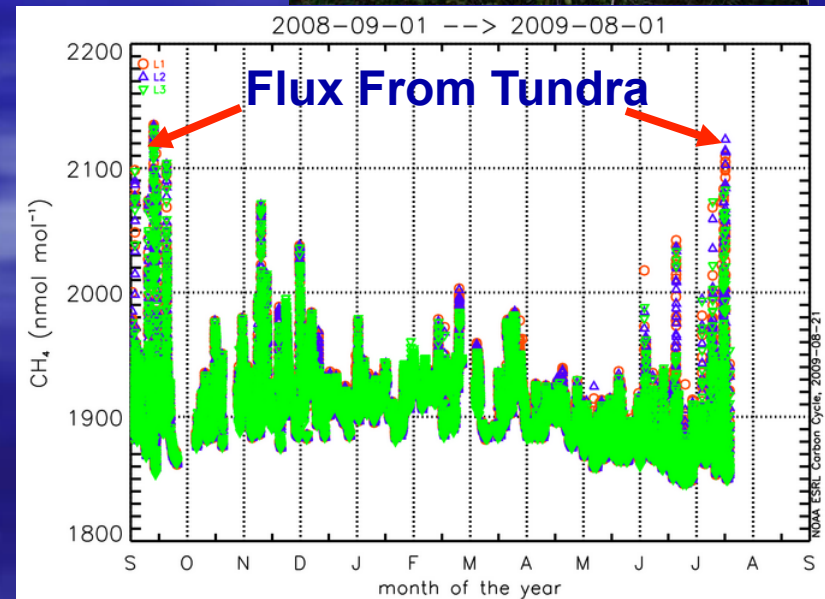
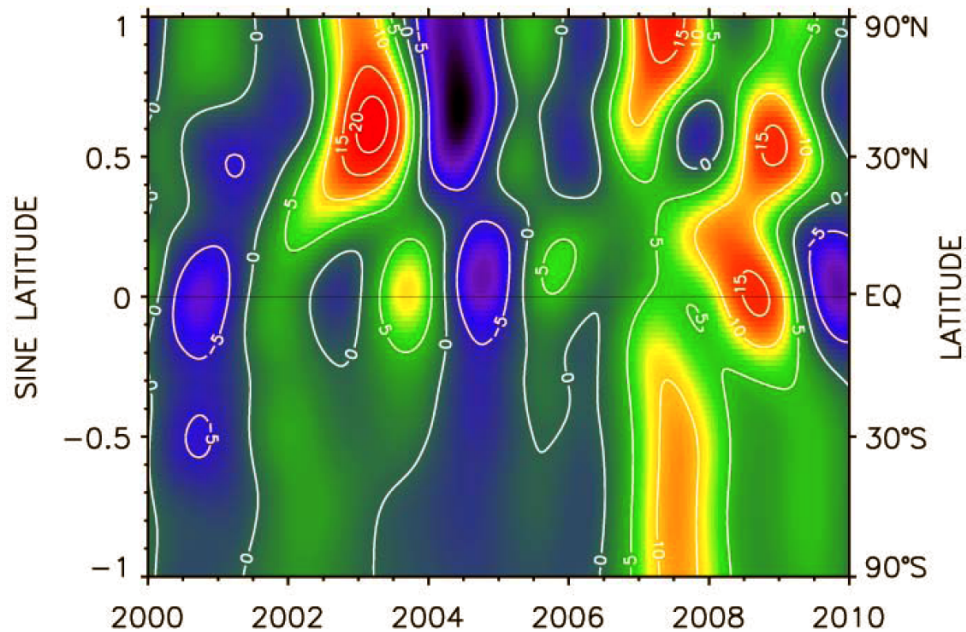
Blue = uptake

Red = source

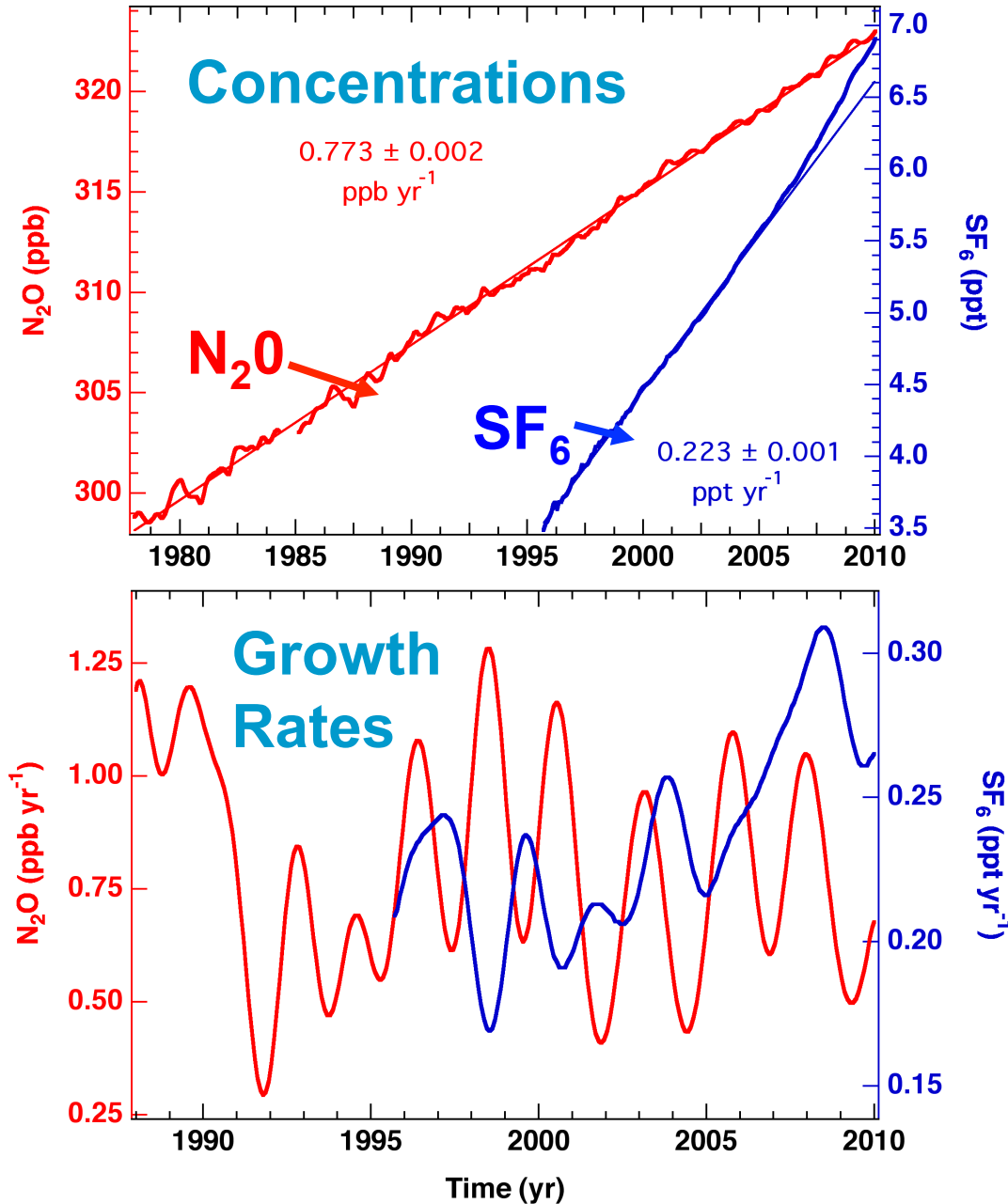


Atmospheric Methane

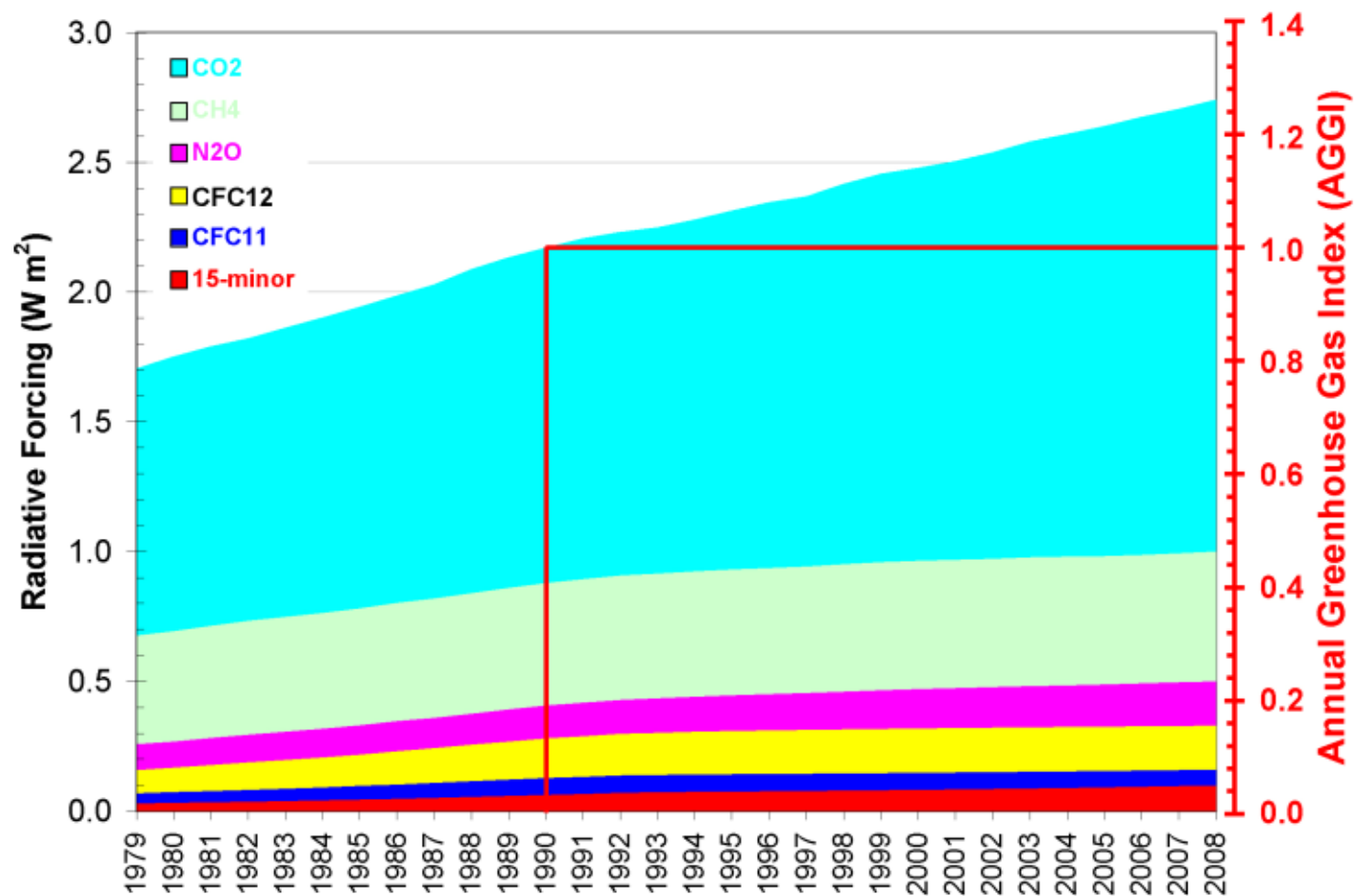
Cherskii,
Russia
Tundra
CH₄
Measure-
ments

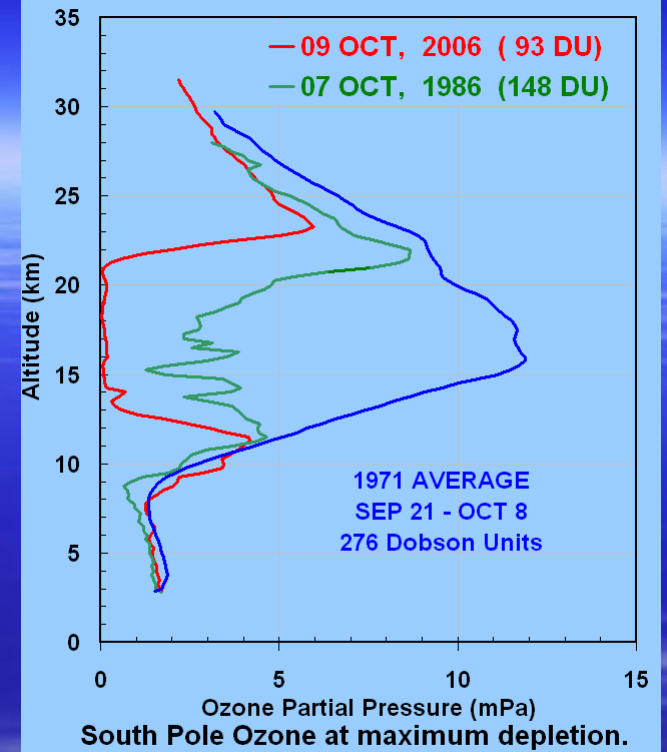
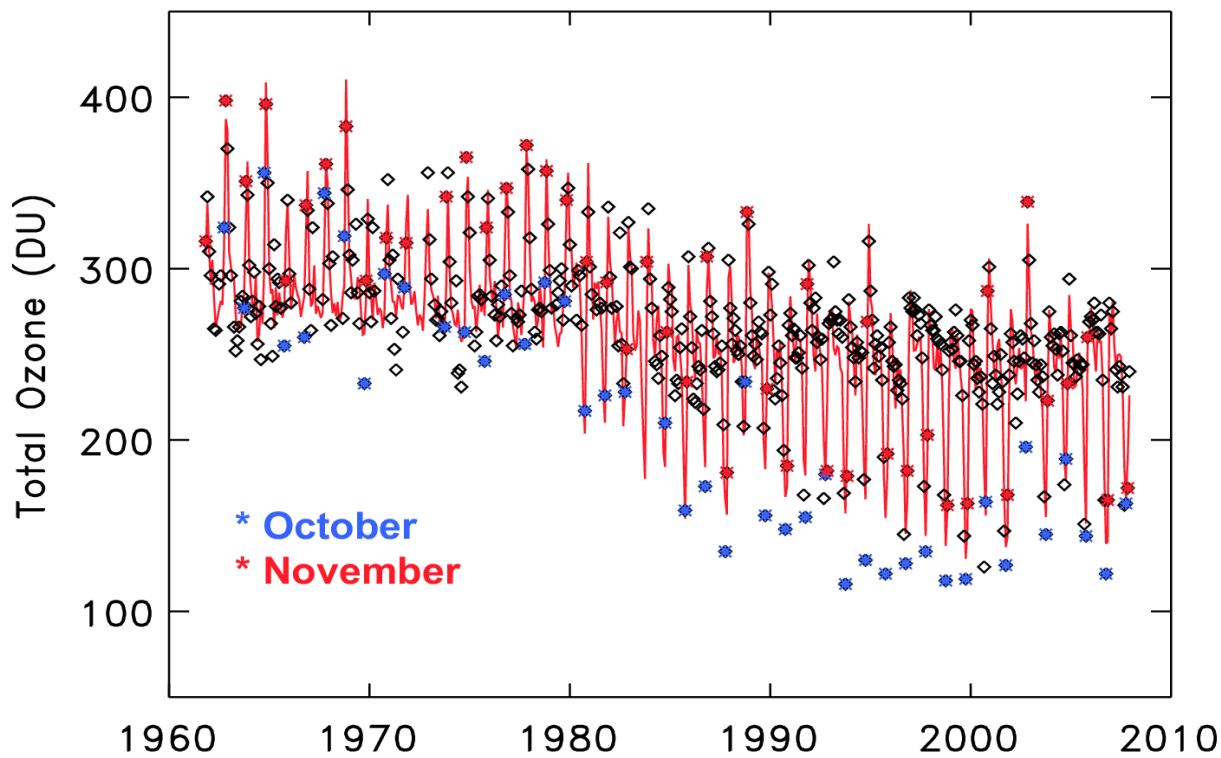


N₂O and SF₆
Important
greenhouse
gases are
steadily
increasing.

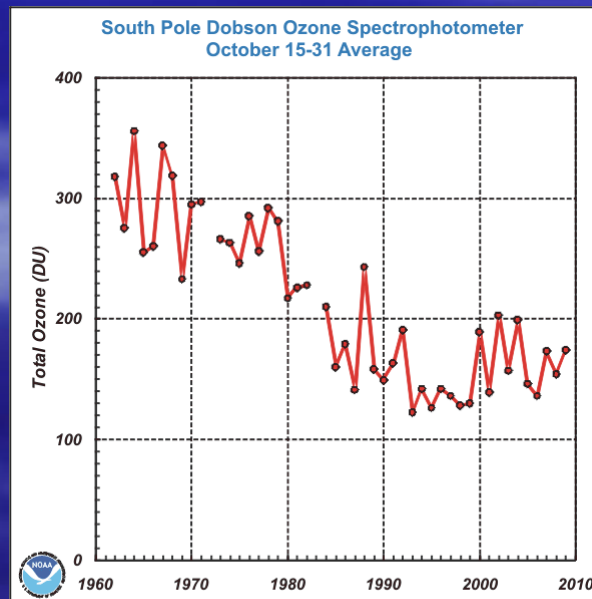


Annual Greenhouse Gas Index

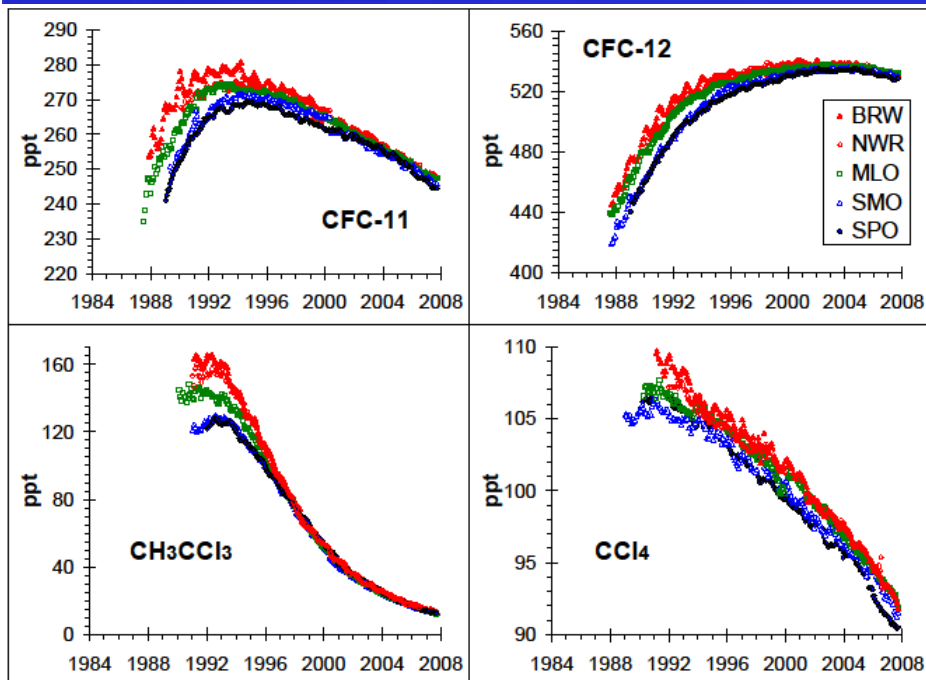




**South Pole
 monthly column
 ozone at with a
 seasonal model
 (above) and
 October 15-31
 average (right)**

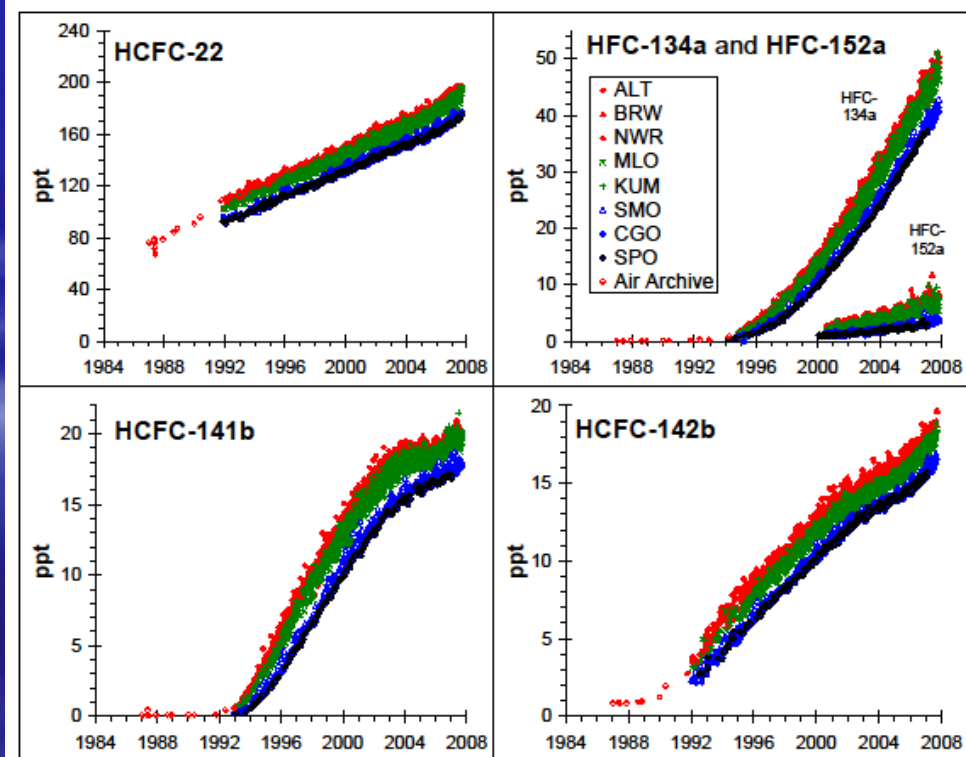


**Ozone profiles at
 South Pole showing
 the dramatic
 stratospheric spring
 ozone depletion on
 October 9, 2006. (red
 curve)**

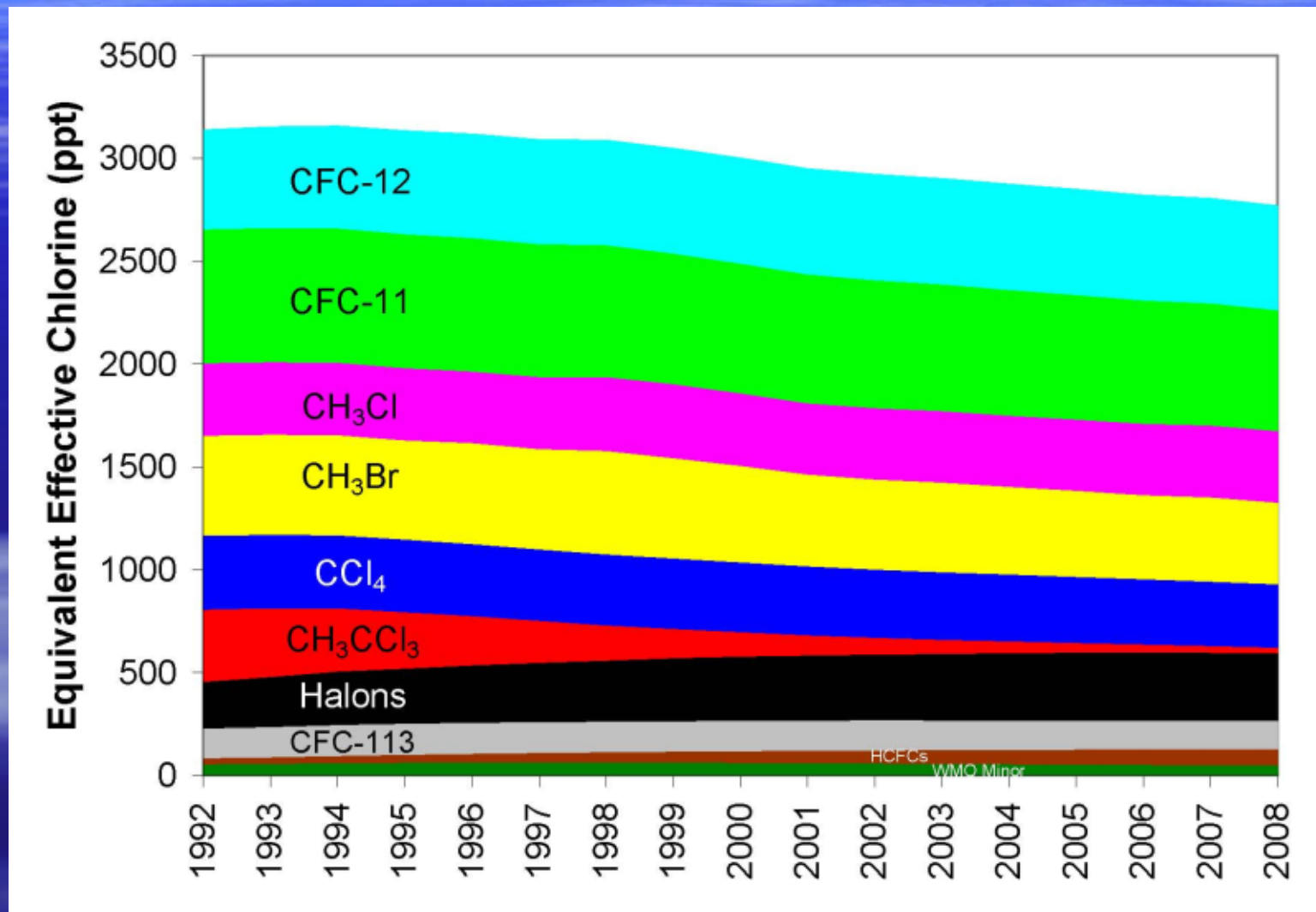


**Global CFC
Trends: CFCs
Destroy
Stratospheric
Ozone**

**HCFCs and HFCs
Are Replacing
CFCs : Less Harm
to Stratospheric
Ozone**



Ozone Depleting Gas Index



Comparison of ground-based column ozone data with satellite observations

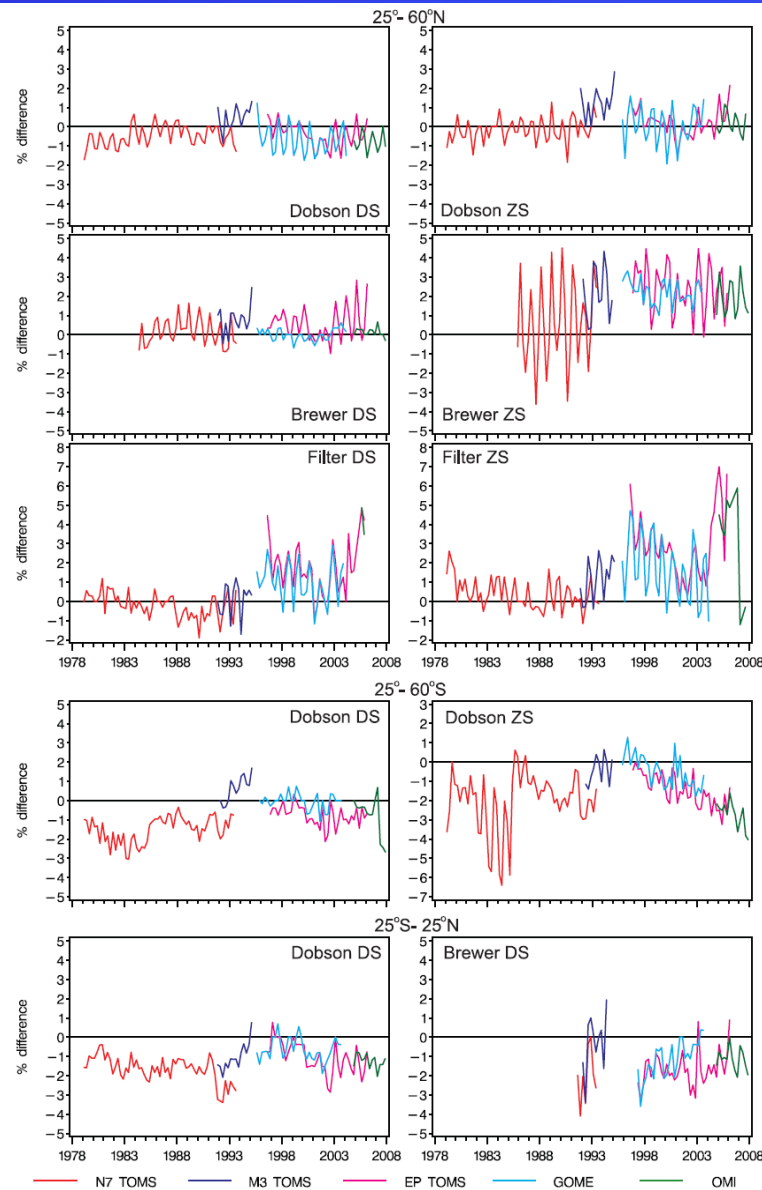
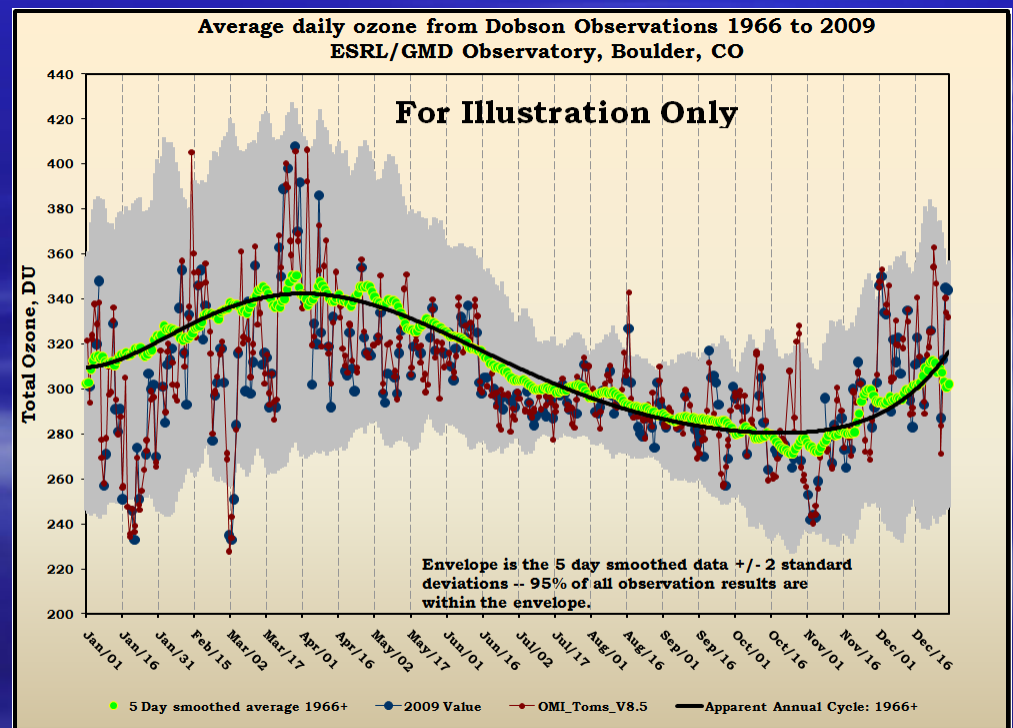
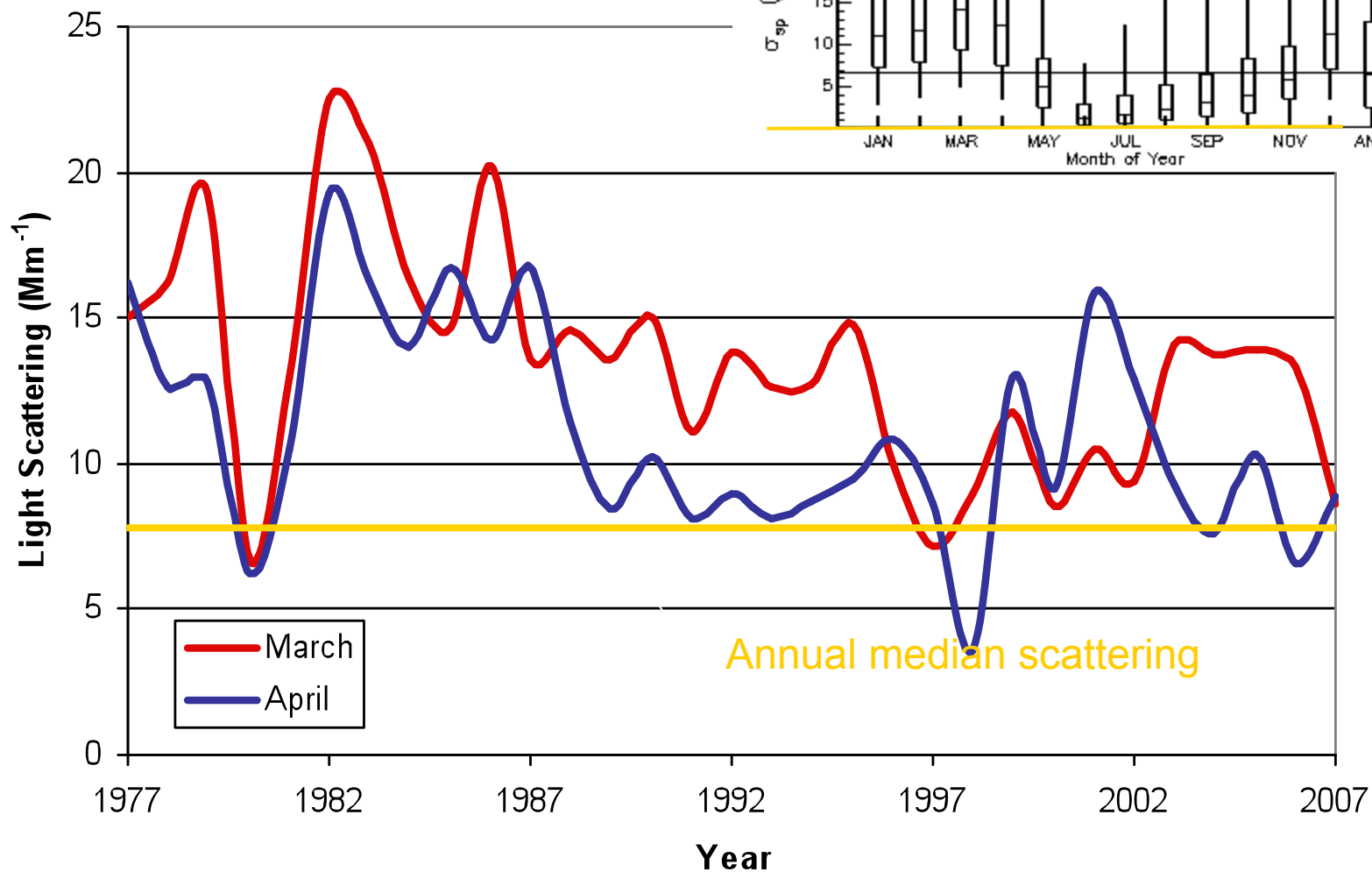


Figure 2. Difference between Dobson and Brewer daily total ozone values and data from different satellites over 25–60°N, 25–60°S, and the tropical region (25°S–25°N). Each point on the plot represents the median value of the difference for a season. Calculations were done for DS and ZS measurements separately.

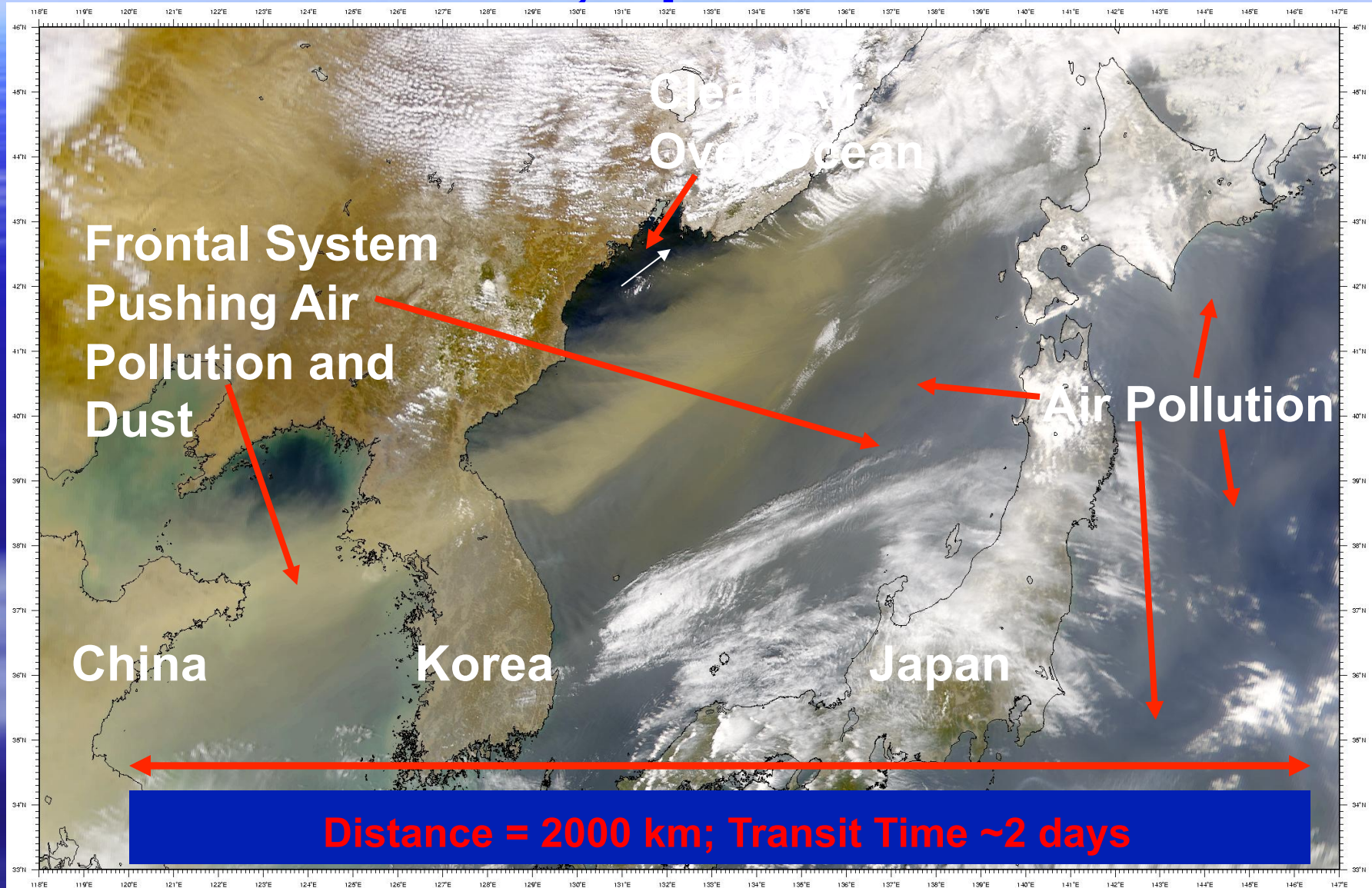


Monthly averaged scattering for **March** and **April** at BRW

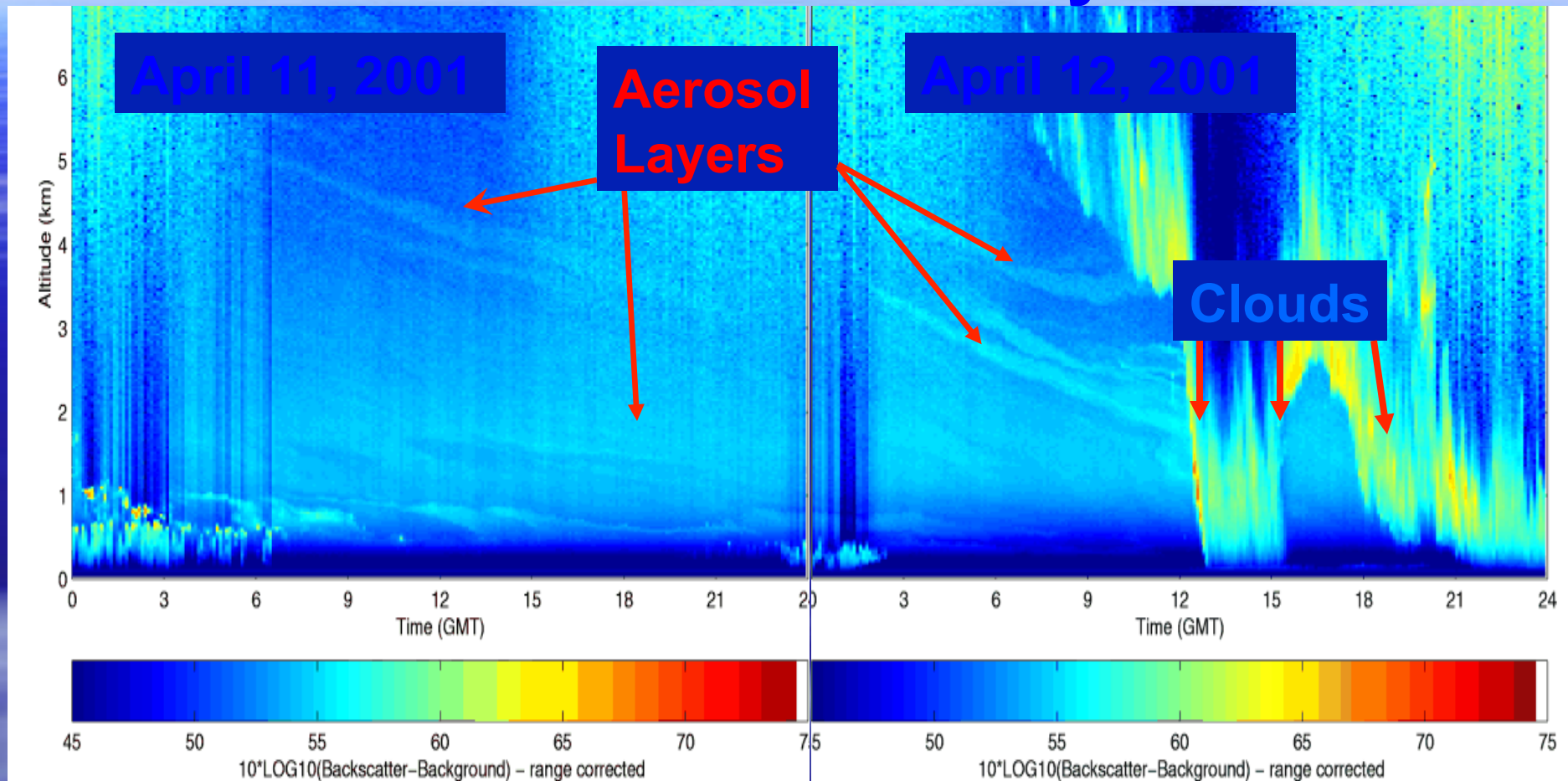
Annual light scattering statistics at BRW



Dust and Air Pollution Flowing Out of Asia, April 2001

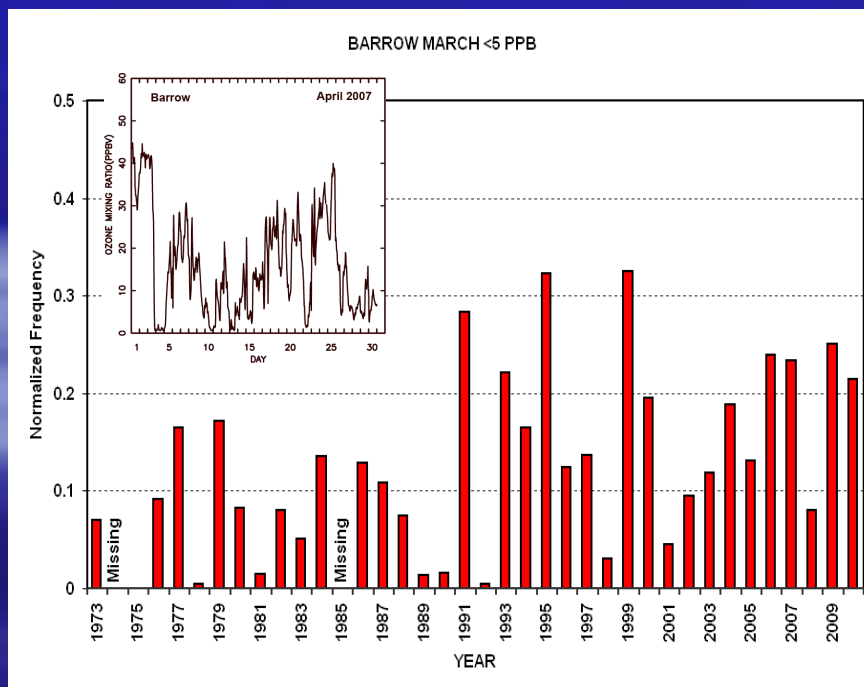
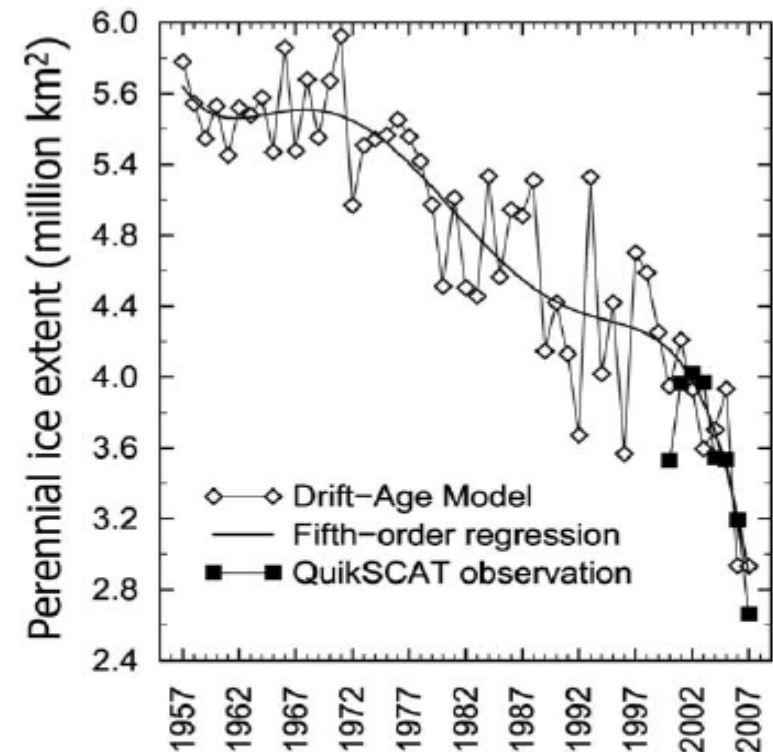


Lidar Observed Asian Aerosols, Barrow Observatory



- Asian gases and aerosols flow to the Arctic.
- The gases and aerosols may be transported in thin layers.

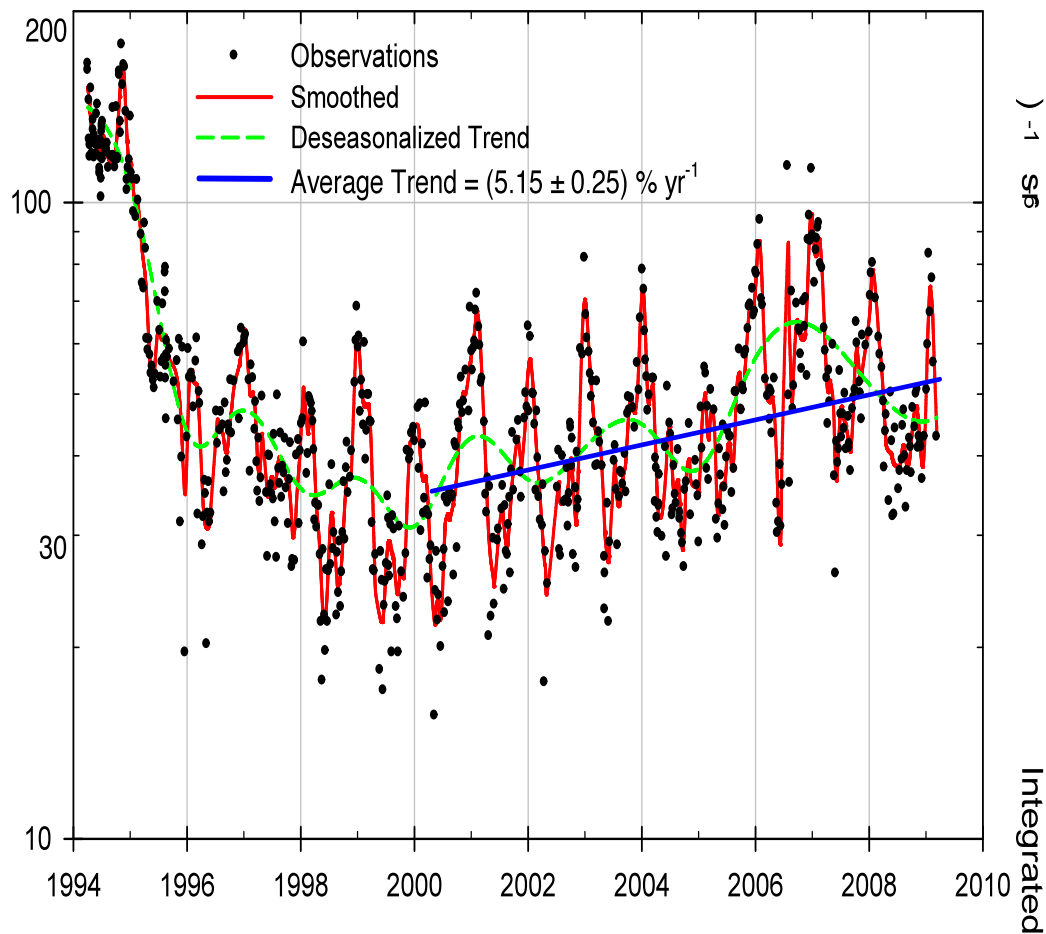
Change in area of perennial sea ice extent in March (from S.V. Nghiem et al., GRL, 2007)
Greater proportion of annual ice may lead to more efficient processing of halogen compounds – more open leads and brinier ice cover



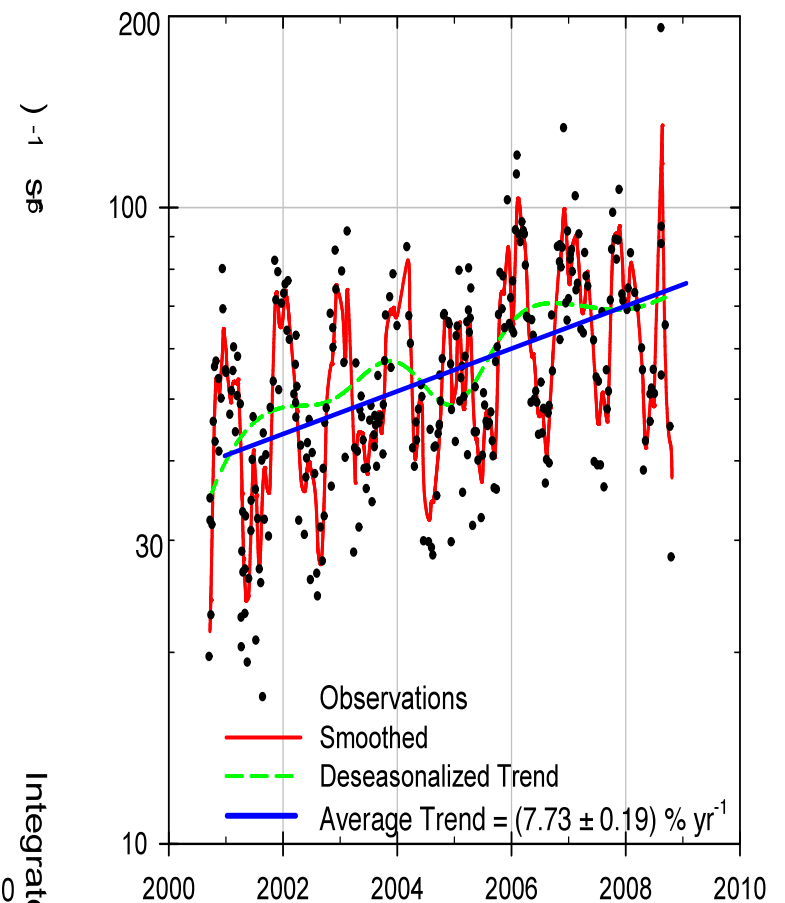
Frequency (normalized hours) of Ozone Mixing Ratios ≤ 5 at Barrow Each Year for March

INTEGRATED LIDAR BACKSCATTER - 20 - 25 km

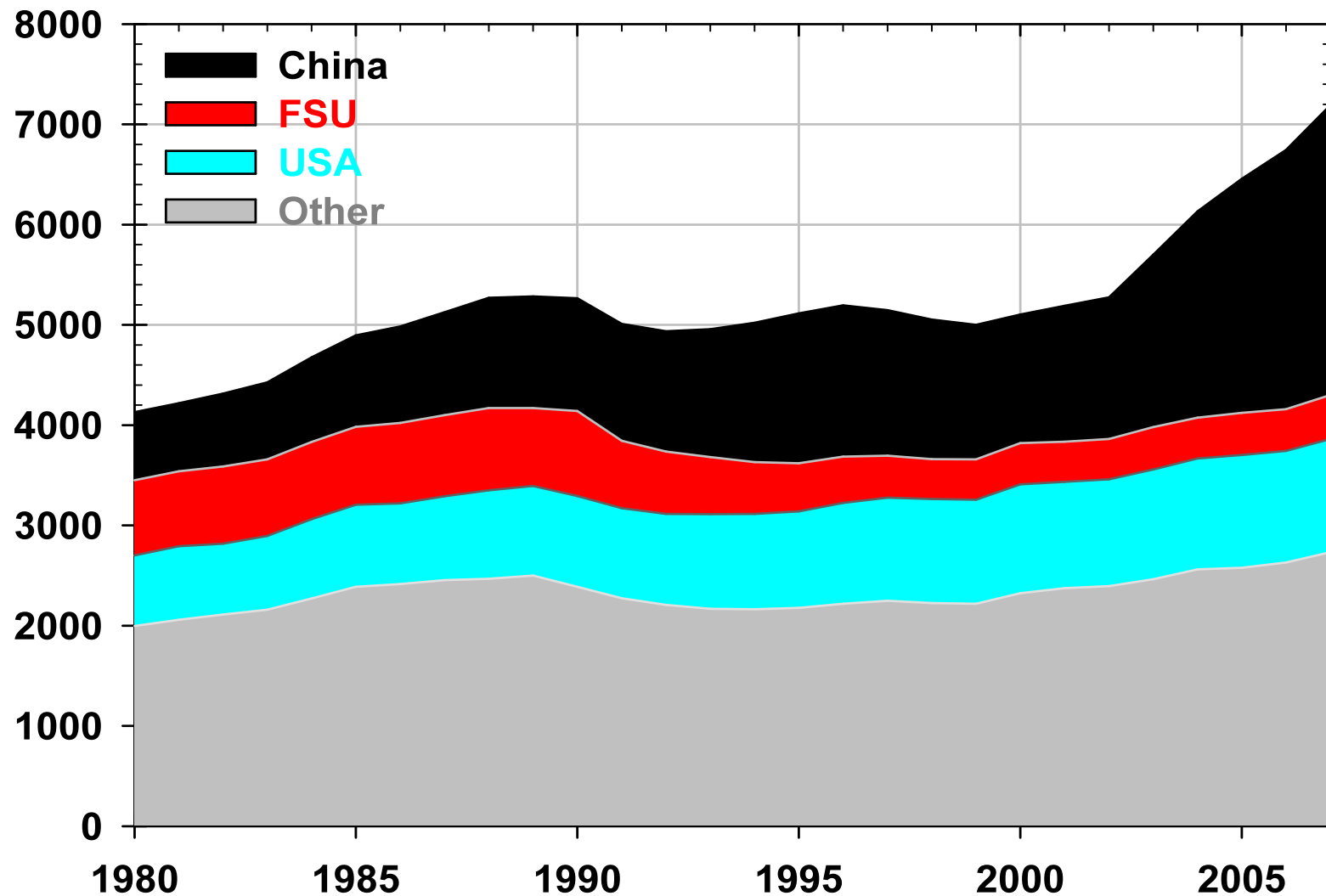
Mauna Loa Observatory



Boulder, Colorado



World Coal Consumption



The recent increase in coal consumption is mainly in China

Maintaining Measurement and Data Integrity

- Each project has one or more scientists responsible for the measurements.
- Observations are tied to international standards where they exist. GMD is the World Meteorological Calibration Facility for CO₂, CH₄, CO, N₂O, Dobson Total Ozone.
- The GMD Standards Lab produces reference gases for 55 atmospheric trace gases.
- Observations are archived at international data centers for greenhouse gases, ozone, aerosols, and radiation as well as the GMD maintained web/ftp sites (<http://www.esrl.noaa.gov/gmd/>)

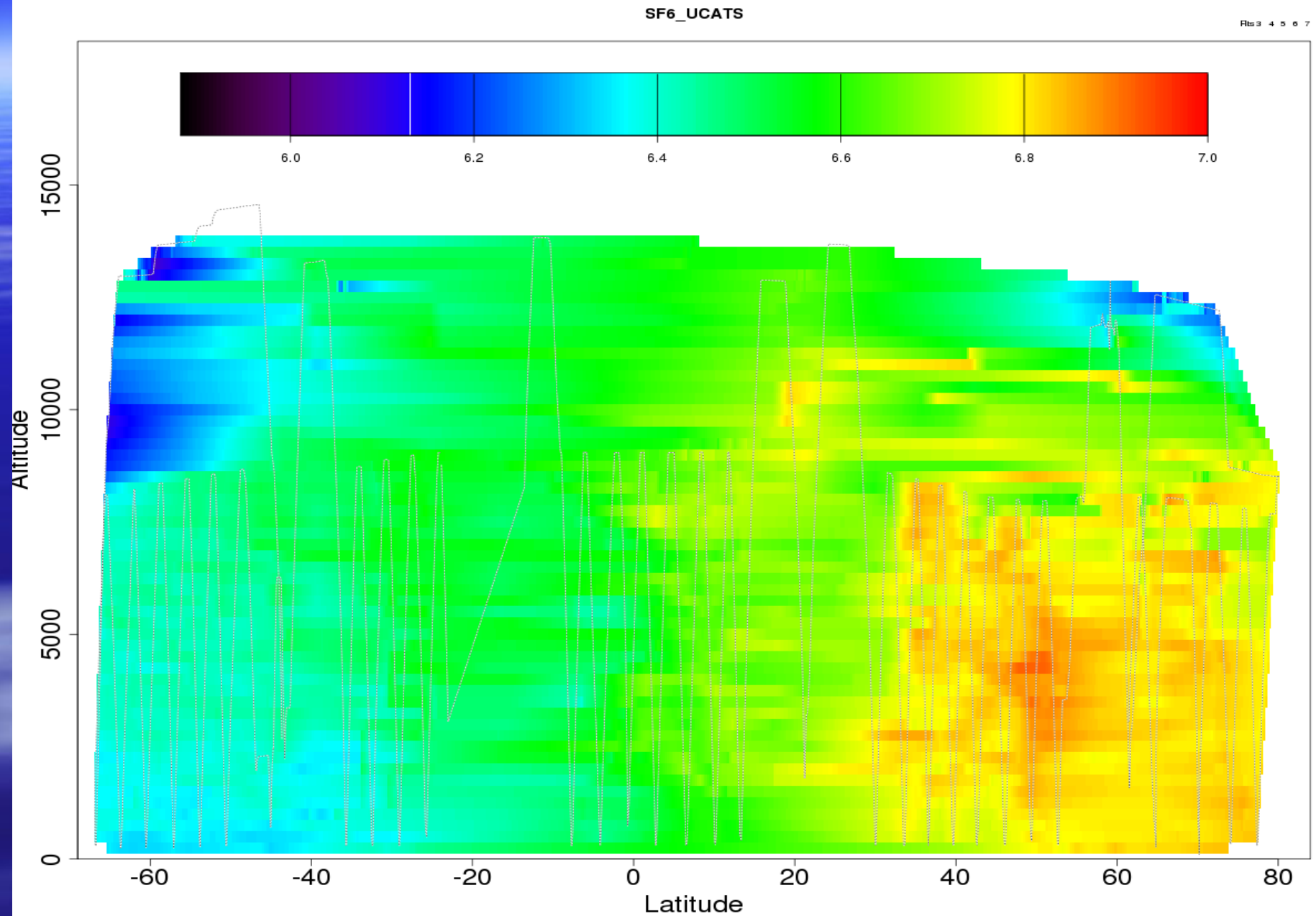
We are active participants in international observing networks and data centers

- **Global Atmosphere Watch (GAW) of the World Meteorological Organization**
- **Baseline Surface Radiation Network (BSRN)**
- **Network for Detection of Atmospheric Composition Change (NDACC)**
- **Southern Hemisphere Additional Ozonesondes (SHADOZ)**
- **World Data Center for Greenhouse Gases**
- **World Ozone and Ultraviolet Radiation Data Center**
- **Others for radiation and aerosols**

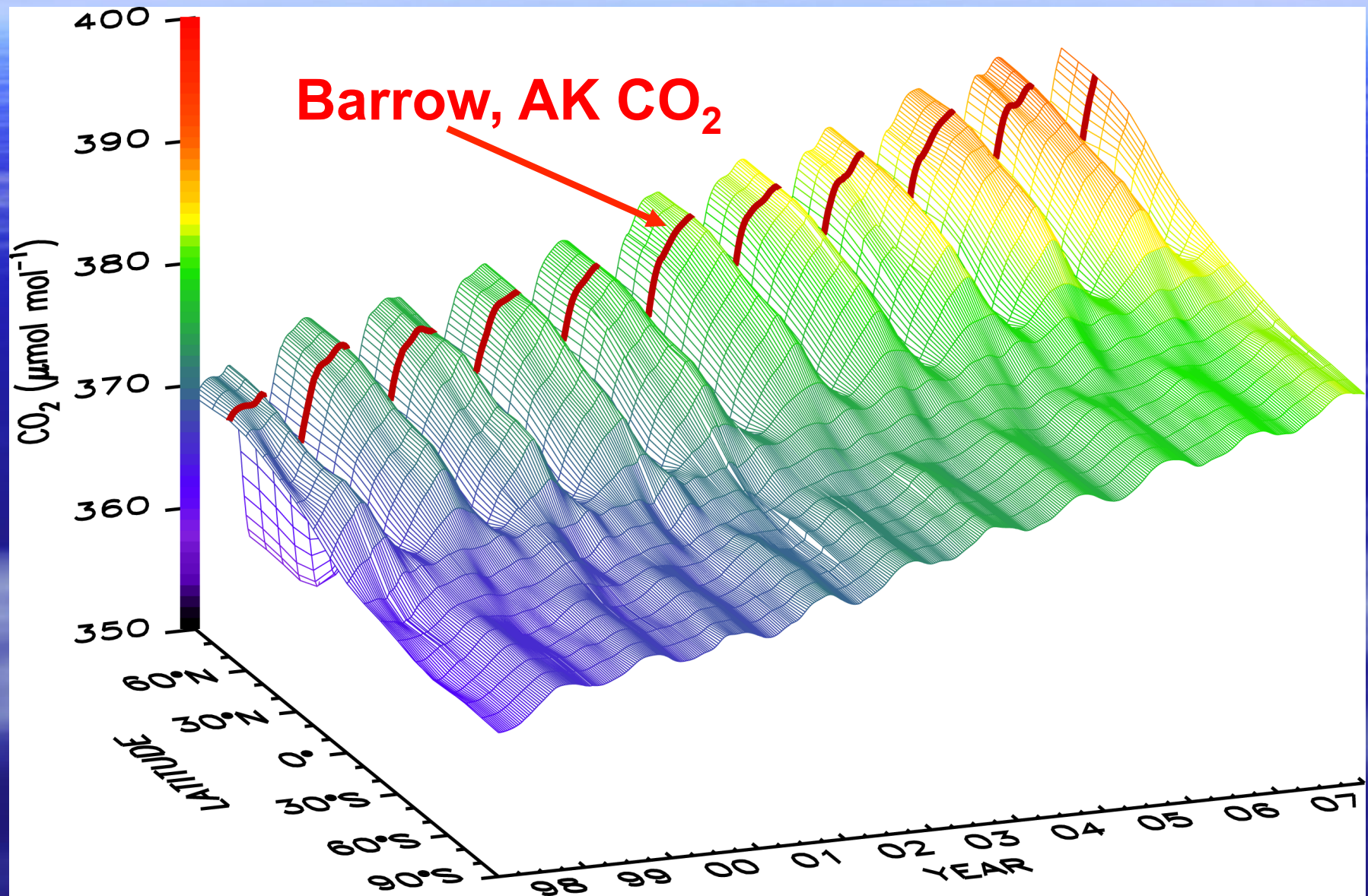
Summary

- NOAA/ESRL/GMD carries out a comprehensive program of atmospheric constituent and radiation observations.
- The integrity of these measurements is maintained through strong scientific leadership and continuity.
- The observations are used for a variety of purposes (research, monitoring, validation, public information),
- The data are archived and available through several sources including international data centers.

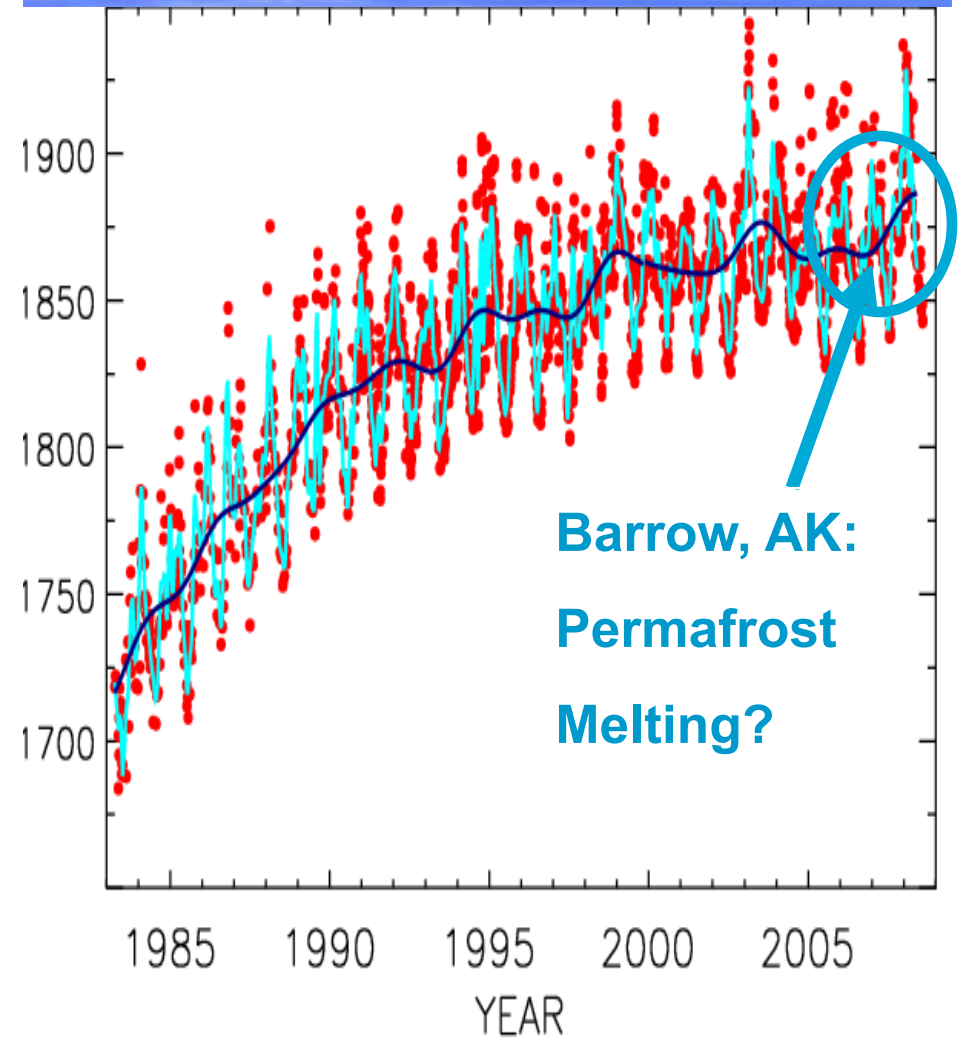
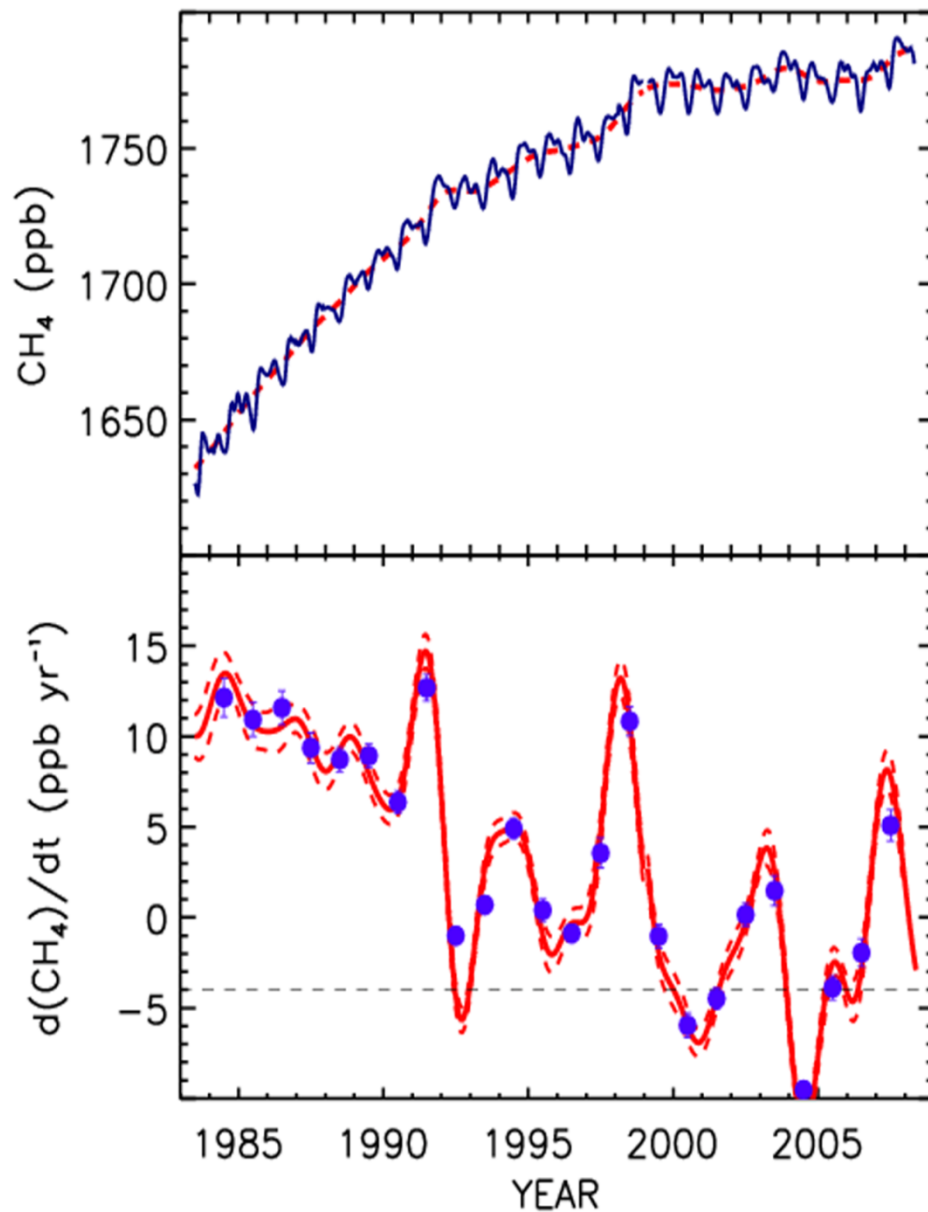
SF₆, HIPPO-1, Jan 2009



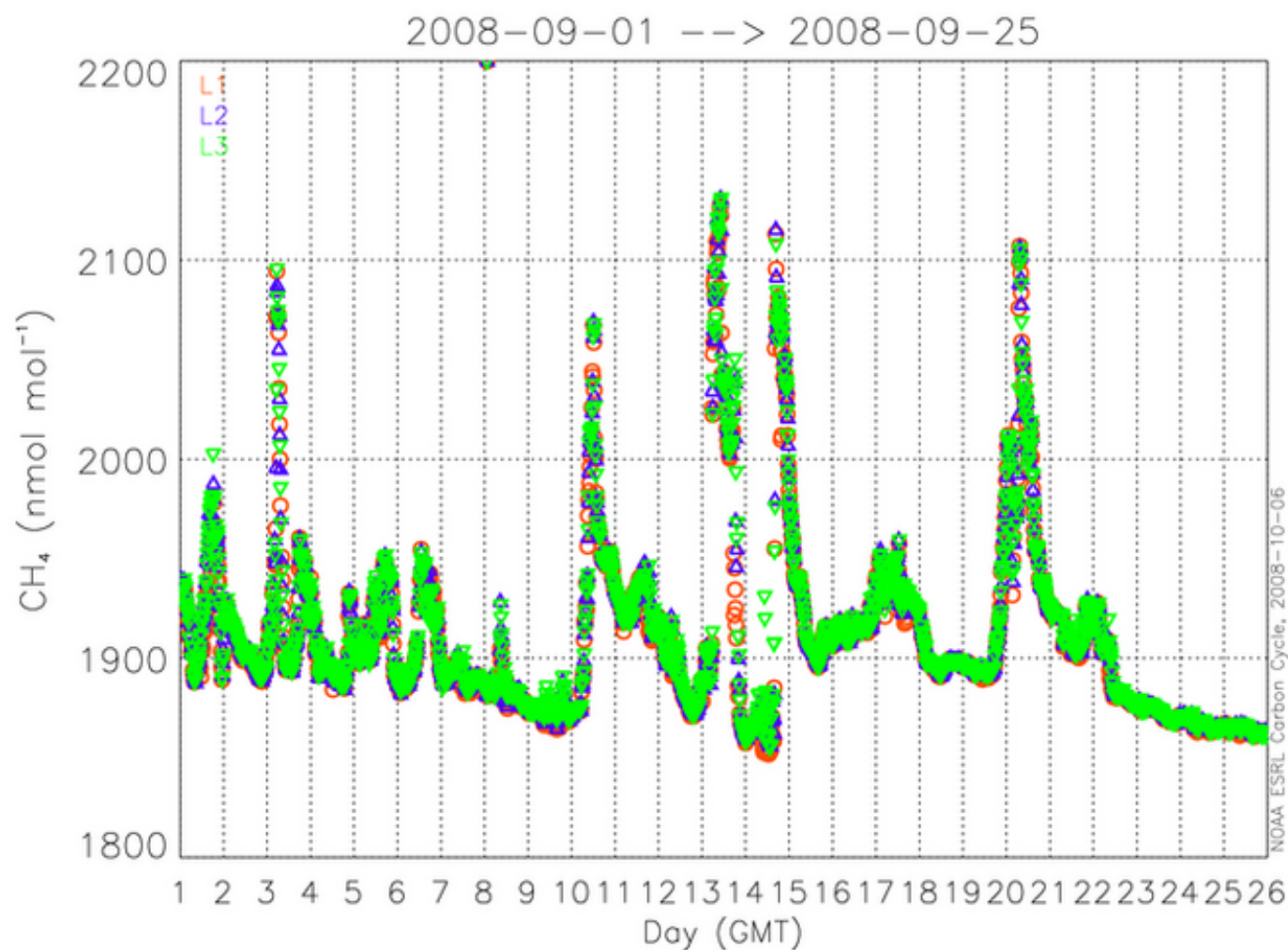
Global Carbon Dioxide Cycle



Global Methane



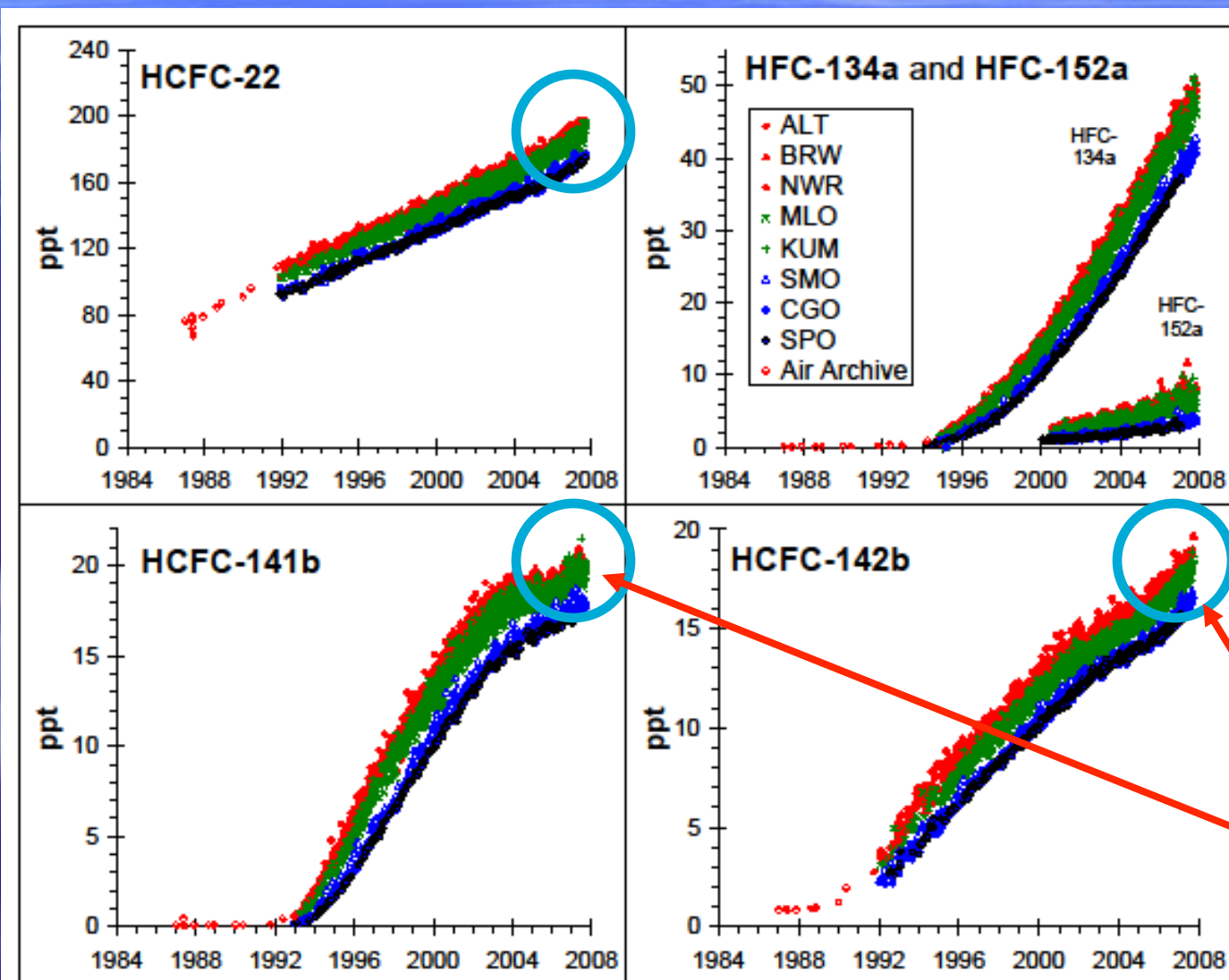
Methane Measurements Cherskii, Russia September 2008



Trans-Siberian Observations Into Chemistry of the Atmosphere (TROICA)



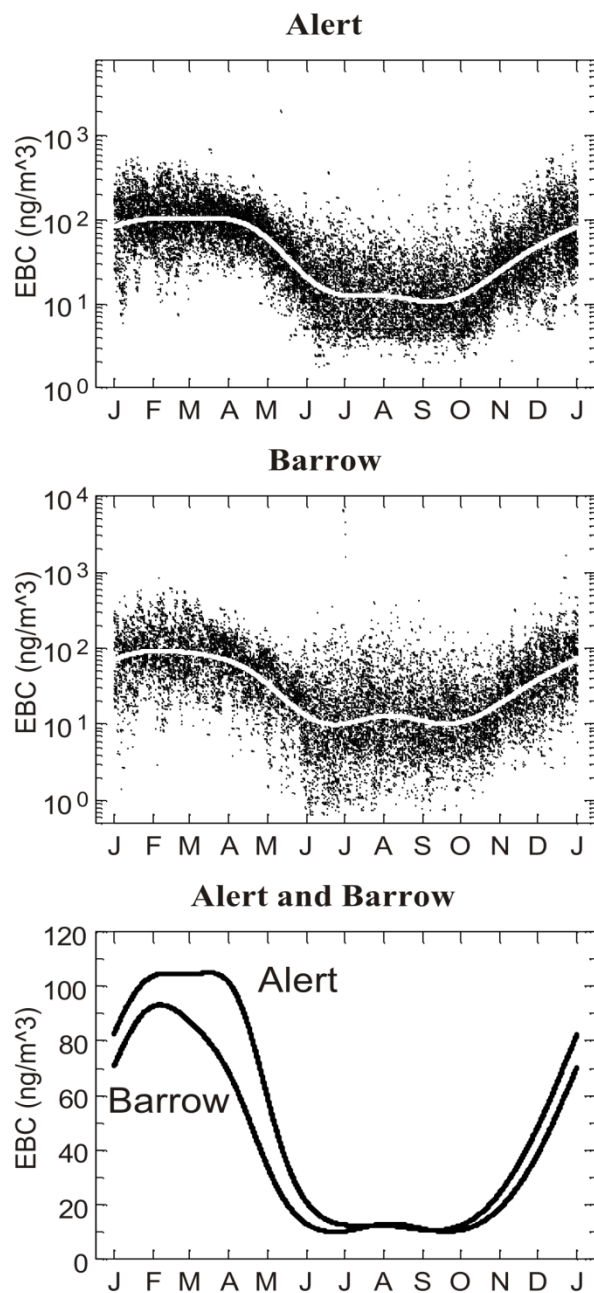
HCFCs Are Replacing CFCs and HFCs: Less Harm to Stratospheric Ozone



Cherskiy, Russia Tundra CH₄ Measurements (Summer 2008)



Arctic Black Carbon and Aerosol Optical Depth



(left) Annual black carbon at Barrow and Alert.
(below) Barrow aerosol optical depth (1978-02).

